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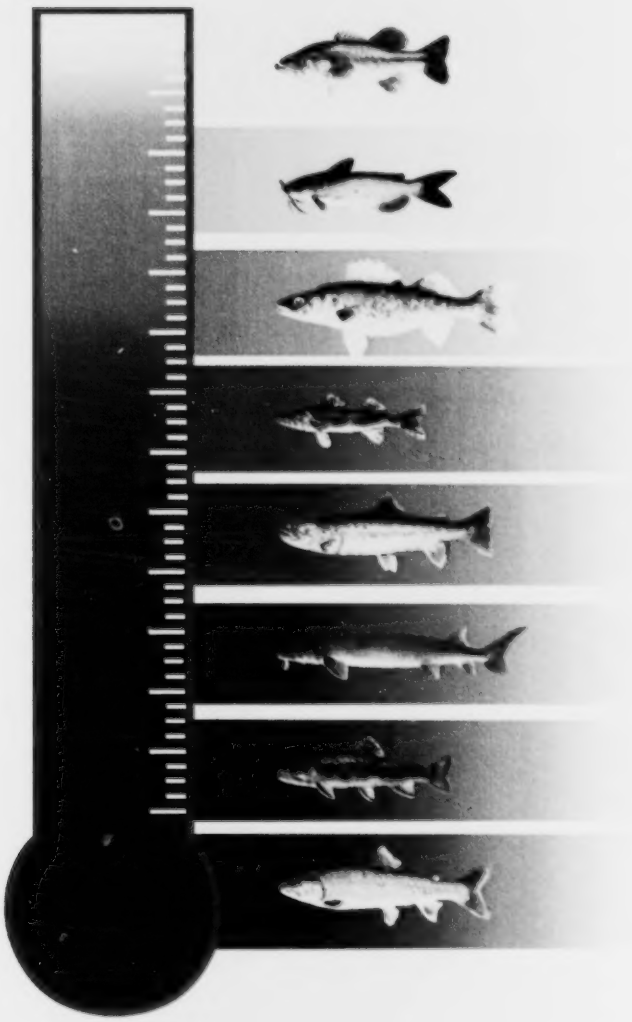
CLIMATE CHANGE RESEARCH REPORT CCRR-17

Key Ecological Temperature Metrics for Canadian Freshwater Fishes



Responding to Climate Change Through Partnership

Ministry of Natural Resources

Natural. Valued. Protected.

Ontario

Climate Change and MNR: A Program-Level Strategy and Action Plan

The following describes how the Ministry of Natural Resources works to contribute to the Ontario Government's commitment to reduce the rate of global warming and the impacts associated with climate change. The framework contains strategies and sub-strategies organized according to the need to understand climate change, mitigate the impacts of rapid climate change, and help Ontarians adapt to climate change:

Theme 1: Understand Climate Change

Strategy #1: Gather and use knowledge in support of informed decision-making about climate change. Data and information gathering and management programs (e.g., research, inventory, monitoring, and assessment) that advances our knowledge of ecospheric function and related factors and forces such as climate change are critical to informed decision-making. Accordingly, MNR will work to:

- Strategy 1.A: Develop a provincial capability to describe, predict, and assess the important short- (0-5 years), medium- (5-20 years), and long-term (20+ years) impacts of climate change on the province's ecosystems and natural resources.
- Strategy 1.B: Model the carbon cycle.

Strategy #2: Use meaningful spatial and temporal frameworks to manage for climate change. A meaningful spatial and temporal context in which to manage human activity in the ecosphere and address climate change issues requires that MNR continue to define and describe Ontario's ecosystems in-space and time. In addition, MNR will use the administrative and thematic spatial units required to manage climate change issues.

Theme 2: Mitigate the Impacts of Climate Change

Strategy #3: Gather information about natural and cultural heritage values and ensure that this knowledge is used as part of the decision-making process established to manage for climate change impacts. MNR will continue to subscribe to a rational philosophy and corresponding suite of societal values that equip natural resource managers to take effective action in combating global warming and to help Ontarians adapt to the impacts of climate change.

Strategy #4: Use partnership to marshal a coordinated response to climate change. A comprehensive climate change program involves all sectors of society as partners and participants in decision-making processes. The Ministry of Natural Resources will work to ensure that its clients and partners are engaged.

Strategy #5: Ensure corporate culture and function work in support of efforts to combat rapid climate change. Institutional culture and function provide a "place" for natural resource managers to develop and/or sponsor proactive and integrated programs. The Ministry of Natural Resources will continue to provide a "home place" for the people engaged in the management of climate change issues.

Strategy #6: Establish on-site management programs designed to plan ecologically, manage carbon sinks, reduce greenhouse gas emissions, and develop tools and techniques that help mitigate the impacts of rapid climate change. On-site land use planning and management techniques must be designed to protect the ecological and social pieces, patterns, and processes. Accordingly, MNR will work to:

- Strategy 6.A: Plan ecologically.
- Strategy 6.B: Manage carbon sinks.
- Strategy 6.C: Reduce emissions.
- Strategy 6.D: Develop tools and techniques to mitigate the impacts of rapid climate change.

Theme 3: Help Ontarians Adapt

Strategy #7: Think and plan strategically to prepare for natural disasters and develop and implement adaptation strategies. MNR will sponsor strategic thinking and planning to identify, establish, and modify short- and long-term direction on a regular basis. Accordingly, MNR will work to:

- Strategy 7.A: Sponsor strategic management of climate change issues.
- Strategy 7.B: Maintain and enhance an emergency response capability.
- Strategy 7.C: Develop and implement adaptation strategies for water management and wetlands.
- Strategy 7.D: Develop and implement adaptation strategies for human health.
- Strategy 7.E: Develop and implement adaptation strategies for ecosystem health, including biodiversity.
- Strategy 7.F: Develop and implement adaptation strategies for parks and protected areas for natural resource-related recreational opportunities and activities that are pursued outside of parks and protected areas.
- Strategy 7.G: Develop and implement adaptation strategies for forested ecosystems.

Strategy #8: Ensure policy and legislation respond to climate change challenges. Policy, legislation, and regulation guide development and use of the programs needed to combat climate change. MNR will work to ensure that its policies are proactive, balanced and realistic, and responsive to changing societal values and environmental conditions.

Strategy #9: Communicate. Ontarians must understand global warming, climate change, and the known and potential impacts in order to effectively and consistently participate in management programs and decision-making processes. Knowledge dissemination through life-long learning opportunities that are accessible and current is critical to this requirement. MNR will raise public understanding and awareness of climate change through education, extension, and training programs.

Key Ecological Temperature Metrics for Canadian Freshwater Fishes

Sarah S. Hasnain[1], C. Ken Minns[1, 2], Brian J. Shuter[3, 2]

[1] Great Lakes Laboratory for Fisheries and Aquatic Sciences
Fisheries and Oceans Canada
Bayfield Institute, 867 Lakeshore Road, P.O. Box 5050
Burlington, ON L7R 4A6 Canada

[2] Department of Ecology and Evolutionary Biology
University of Toronto
25 Willcocks Street
Toronto, ON M5S 3B2 Canada

[3] Harkness Laboratory of Fisheries Research
Aquatic Research and Development Section
Ontario Ministry of Natural Resources
Peterborough, ON K9J 8M5 Canada

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Ontario Forest Research Institute
Ministry of Natural Resources
1235 Queen Street East
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Canada P6A 2E5

Telephone: (705) 946-2981
Fax: (705) 946-2030
E-mail: information.ofri@ontario.ca

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Abstract

Habitat temperature is a major determinant of performance and activity in fish. We examined the relationship between six temperature metrics describing the growth (optimal growth temperature and final temperature preferendum), survival (upper incipient lethal temperature and critical thermal maximum), and reproduction (optimum spawning temperature and optimum egg development temperature) requirements of 87 Canadian freshwater fish species. Our results suggest that all metrics were highly correlated, especially those within each life process. Values for different metrics fell into distinct groups that were associated with thermal preference classes, reproductive guilds, and spawning season. These results suggest that it may be possible to estimate missing metric values using known values. This compilation of metrics provides easy access to information for a broad range of fish species common to North America and should foster more extensive use of this information in fish ecology.

Résumé

Principales mesures de température écologiques pour les poisons d'eaux douce canadiens

La température de l'habitat du poisson est un facteur déterminant de sa performance et de son activité. Nous avons examiné la relation entre six mesures de température correspondant aux exigences de croissance (température de croissance optimale et préférendum de température finale), de survie (température létale initiale et température maximale critique), de reproduction (température de fraie maximale et température optimale pour le développement des œufs) de 87 espèces canadiennes de poissons d'eau douce. Les résultats démontrent que toutes les mesures étaient étroitement corrélées, surtout celles d'un même processus vital. Les valeurs de différentes mesures se regroupaient dans des catégories distinctes associées aux préférences thermales, aux guildes reproductives et aux saisons de fraie. Les résultats laissent croire qu'il pourrait être possible d'estimer les valeurs manquantes à partir des valeurs connues. Cette compilation de mesures permet d'accéder facilement aux données d'une large gamme d'espèces de poissons communes en Amérique du Nord et devrait favoriser l'utilisation de ces données en ce qui a trait à l'écologie du poisson.

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Elizabeth and Alexandra Birk-Urovitz compiled the first version of the metrics database and undertook preliminary statistical analyses. Their contribution to this work is gratefully acknowledged. Nick Jones and Paul Gray provided very useful comments on an earlier draft of this report. Support for this work was provided by the Department of Fisheries and Oceans, the Ontario Ministry of Natural Resources, and the University of Toronto. We thank Lisa Buse for editorial assistance and Trudy Vaittinen for layout and graphic design.

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Introduction

Temperature is one of the most important abiotic factors influencing fish survival and performance (Brett 1971, Christie and Regier 1988). According to the thermal primacy paradigm developed by Brett (1956), the fundamental requirement for fishes is "an external temperature most suitable to internal temperature". Fry (1947) noted that the survival and growth of fish depend on relationships between external environmental factors and internal metabolic processes. As fish are obligate poikilothermic ectotherms, their body temperatures are equal to or within a few fractions of a degree of the surrounding water temperature (Wood and McDonald 1997, Beitinger et al. 2000). Therefore, they are highly dependent on water temperature to maintain important biochemical, physiological, and life history processes (Wood and McDonald 1997, Beitinger et al. 2000). Previous studies have shown that the reaction rates for many critical processes "rise slowly as the preferred temperature is approached from below, and drop rapidly after it is exceeded until reaching zero at the lethal temperature"(Kling et al. 2003). This indicates that physiological performance is maximized within a narrow temperature range and that, depending on the species, optimal temperatures for many processes centre around a specific value (Brett 1971, Hokanson 1977, Beitinger and Fitzpatrick 1979, Jobling 1994).

Environmental thermal conditions are also important determinants of reproductive success. Processes such as spawning and egg development require specific thermal conditions and are sensitive to water temperature perturbations (Van der Kraak and Pankhurst 1997). Increases in temperature of only 2 C° above normal can result in eggs with abnormal cleavage patterns leading to decreased hatching success (Van der Kraak and Pankhurst 1997). High temperatures have been shown to also arrest development, causing damage to both previtellogenic and mature oocytes (Chimlevsky 1999). In addition, changes in temperature can shift the balance between oxygen availability in the environment and oxygen demand by internal metabolic processes, in ways that lead directly to mortality among eggs and/or embryos (Alderdice et al. 1958, Rombough 1997, Evans 2007).

Given the importance of water temperature for fish physiological and reproductive activities, it is important to assess the relationships among the various metrics that characterize fish thermal requirements. The objectives of this study were twofold: (1) to compile a comprehensive database summarizing the available data on temperature metrics for growth, reproduction, and survival of Canadian freshwater fish species, and (2) to identify correlations and groupings among those metrics.

In this study, we compared two metrics for each of the three processes: growth, survival, and reproduction. For growth, we compiled optimum growth and final temperature preferenda. For survival, we compiled upper incipient lethal temperatures and critical thermal maxima, and for reproduction, we compiled optimal spawning and egg development temperatures.

We predicted that due to similarities in temperature requirements for processes within each stage, measures within a stage would be more positively correlated with one another than with other measures. We also expected values for each metric to co-vary with life history characteristics such as temperature preference class, reproductive guild, and spawning season.

Methods

Data collection

Metric values were compiled for 87 Canadian freshwater fish species. Only freshwater fish species occurring in Canada were considered. Species were evaluated only when data were available for one or more thermal metrics and information was not collected for extinct or extirpated species, or for hybrid forms. A complete list of the species for which data were compiled (with scientific names) is provided in the Appendix (Tables A1-3) along with the sources for the metric values.

For each species, the following thermal metrics and life history characteristics were compiled: optimum growth temperature, final temperature preferendum, upper incipient lethal limit, critical thermal maximum, spawning temperature, egg development temperature, temperature preference class, spawning season, and reproductive guild. A list of temperature metrics and life history characteristics for each species is provided in the Appendix. All metric estimates were derived using adult members of each species.

Species-specific temperature metrics were first compiled from secondary literature sources. The main texts used were:

- *Freshwater Fishes of Canada* (Scott and Crossman 1987)
- *Morphological and Ecological Characteristics of Canadian Freshwater Fishes* (Coker et al. 2001)
- *Temperature Relationships of Great Lakes Fishes: A Data Compilation* (Wismer and Christie 1987)
- *Temperature Requirements of Fishes from Eastern Lake Erie and the Upper Niagara River: A Review of Literature* (Spotila et al. 1979)
- *Temperature Tolerances and the Final Temperature Preferenda for the Assessment of Optimum Growth Temperature* (Jobling 1981)
- *Acute and Final Temperature Preferenda as Predictors of Lake St. Clair Fish Catchability* (Danzman et al. 1991)
- *Temperature Tolerances of North American Freshwater Fishes Exposed to Dynamic Changes in Temperature* (Beitinger et al. 2000)

Information from these sources was supplemented by species-specific primary and secondary literature cited in these references and primary literature sources published between 1980 and 2009, gathered through a literature search based on the ISI Web of Knowledge (http://isiwebofknowledge.com/). Only peer-reviewed sources and government publications were considered.

Thermal metrics

(i) Growth

Optimum growth temperature (OGT): The optimum growth temperature is that which supports the highest growth rate in an experiment where separate groups of fish are exposed to one of a set of constant temperatures under *ad libitum* feeding conditions. The range of these constant temperatures is chosen so that reduced growth is observed at both extremes (McCauley and Casselman 1980 cited in Wismer and Christie 1987, Jobling 1981).

Final temperature preferendum (FTP): Final temperature preferendum is that towards which fish gravitate when exposed to an 'infinite' temperature range (Giattina and Garton 1982 cited in Wismer and Christie 1987). Two methods are used to determine FTP: the gravitation method and the acclimation method (Jobling 1981). The gravitation method involves exposing fish to a temperature gradient until they gravitate towards a specific temperature. The acclimation method extends the gravitation method by carrying out repeated 'gravitation trials' with fish acclimated to progressively higher temperatures. The preferred temperature exhibited in each trial is then plotted against the acclimation temperature and the FTP is the temperature at which the best fit line for these data crosses the line of equality (Jobling 1981). An informal survey of a subset of the original sources indicated that most estimates were determined via the gravitation method. FTP estimates obtained using both methods were compiled in the database.

Thermal preference class: For each species, thermal preference class was determined based on Coker et al.'s (2001) classification, which uses preferred summer water temperature to classify species as follows: *warm* – >25°C, *cool* – 19 to 25°C, and *cold* – <19°C. A species could occupy one of two intermediate classes, i.e., *cool/cold* or *warm/cool* if their preferred termperature overlaps classes.

(ii) Survival

Upper incipient lethal temperature (UILT): The upper incipient lethal temperature is that at which 50% of the fish in an experimental trial survive for an extended period (Spotila et al. 1979, Jobling 1981, Wismer and Christie 1987). Testing for UILT involves placing groups of fish in separate baths, each held at a different constant temperature, using a sufficiently wide range of constant temperatures that rapid mortality is observed in some baths whereas slow incomplete mortality occurs in others (Spotila et al. 1979).

Critical thermal maximum (CTMax): The critical thermal maximum is an indicator of 'thermal resistance' and is defined as the temperature at which a fish loses its ability to maintain a 'normal' upright posture in the water (loss of equilibrium; Jobling 1981). It is determined by exposing fish in a tank to steadily increasing water temperatures (typically at a rate of 1 C° min^{-1}) and noting the temperature at which the fish exhibit spasms and loss of equilibrium (Jobling 1981, Wismer and Christie 1987). Remaining at, or above, CTMax results in mortality (Jobling 1981, Wismer and Christie 1987).

(iii) Reproduction

Optimal spawning temperature (OS): The optimum spawning temperature is that at which spawning reaches its peak (Wismer and Christie 1987).

Optimum egg development temperature (OE): The optimum egg development temperature is that at which the rate of successful egg development is highest (Wismer and Christie 1987).

Spawning season: Each species was designated as either a spring or fall spawner using the spawning data cited in Scott and Crossman (1973). Spring spawners were those species that spawn between early April and late June, while fall spawners were species that spawn from early September to late October.

Reproductive guild: The reproductive guild groups fish species by their spawning behaviour. All 87 species were assigned to a reproductive guild based on Coker et al.'s (2001) application of Balon's (1975, 1981) classification system:

A.1 = broadcast spawners pelagophils

A.2 = broadcast spawners lithophils

B.1 = brood hiders lithophils

B.2 = brood hiders aeropsammophils

Quality control

We did not attempt to assess the validity of the methods used to estimate each value for each metric. However, for FTP and UILT, intra-specific replication of estimates was sometimes high enough to identify clearly aberrant values. In these cases, we examined the original references to assess the reliability of the methods used to generate the estimates and we flagged those values (see Table A1 in the Appendix; 7 FTP values are flagged) where the methods did not match the requirements specified for the metric. These values were not included in the species-specific mean values used in the analyses described below. Although a similar assessment would have been ideal for the other metrics as well, typically the degree of intra-specific replication was insufficient to reliably identify apparently aberrant values.

Statistical analyses

For each fish species, means and standard deviations were calculated from the individual estimates for each metric. If a range (instead of a single value) was specified for a metric estimate then the mid-point of that range was used in mean and standard deviation calculations. If only one estimate was available for a metric, this value was taken as the mean (Table 1). Once species-specific mean values for each metric were compiled, covariation between these metric means was assessed using the Pearson correlation coefficient and the Spearman rank

correlation coefficient. For each metric, box and whisker plots were used to compare observed variation across temperature preference classes, reproductive guilds, and spawning season groups.

For families represented by at least 5 species, family mean, family minimum and family maximum values were determined from the appropriate species mean values. All statistical analyses were performed using R statistical software (R Development Core Team 2008).

Results

Of the 87 species listed in the database, growth, survival, and reproduction metric data were complete for 32 (Table 1). For growth metrics, complete FTP and OGT data were available for 52 species. Thermal preference class data were available for all species but survival metrics were complete for only 45 species. Complete data for reproduction metrics, OS and OE, were available for only 48 species but reproductive guild data were complete for all species.

Table 1. *Mean optimum growth temperature (OGT), final temperature preferendum (FTP), upper incipient lethal temperature (UILT), critical thermal maxima (CTMax),optimal spawning temperature (OS), and optimum egg development temperature (OE) data for 87 Ontario freshwater fish species. A dash (-) indicates that no data were found. Species are arranged alphabetically within families. References are listed in Table A1 in the Appendix.*

Family	Common Name	Scientific Name	Temperature °C					
			OGT	FTP	UILT	CTMax	OS	OE
Ascipenseridae	Lake Sturgeon	*Ascipenser fulvescens*	-	11.0	-	-	15	14.5
Amiidae	Bowfin	*Amia calva*	-	30.3	-	37.0	-	-
Anguillidae	American Eel	Anguilla rostrata	25.0	19.9	-	-	-	-
Catostomidae	Bigmouth Buffalo	*Ictiobus cyprinellus*	-	19.8	-	-	16.95	20.5
	Longnose Sucker	*Catostomus catostomus*	-	11.1	26.8	-	10	12.5
	Northern Hog Sucker	*Hypentelium nigricans*	25.6	27.0	29.8	30.8	17.5	17.4
	Quillback	*Carpoides cyprinus*	-	20.5	-	37.2	-	-
	Spotted Sucker	*Minytrema melanops*	-	21.8	-	31.0	-	-
	White Sucker	*Catostomus commersoni*	25.5	23.4	27.8	31.6	15.83	15
Centrarchidae	Black Crappie	*Pomoxis nigromaculatus*	18.0	23.4	33.3	34.9	19.2	18.15
	Bluegill	*Lepomis macrochirus*	29.2	30.2	32.2	40.2	25	23
	Green Sunfish	*Lepomis cyanellus*	28.0	25.4	40.0	36.0	21.9	29.1
	Largemouth Bass	*Micropterus salmoides*	26.6	28.6	31.9	38.4	19.15	20
	Pumpkinseed	*Lepomis gibbosus*	25.0	27.7	31.7	37.6	26	28
	Rock Bass	*Ambloplites rupestris*	28.4	24.9	33.9	36.0	-	-
	Smallmouth Bass	*Micropterus dolomieui*	26.0	25.0	36.0	36.3	18	21
	White Crappie	*Pomoxis annularis*	22.5	19.1	-	32.8	17	19.15
Clupeidae	Alewife	*Alosa pseudoharengus*	20.1	16.9	23.1	31.3	13.75	17.8
	Gizzard Shad	*Dorosoma cependianum*	17.0	20.7	35.5	31.7	22	22.2
Cottidae	Deepwater Sculpin	*Myoxocephalus thompsoni*	-	5.0	-	-	-	-
	Fourhorn Sculpin	*Myoxocephalus quadricornis*	-	5.0	-	-	-	-
	Mottled Sculpin	*Cottus biardii*	-	16.2	24.3	30.9	11.4	12.55
	Slimy Sculpin	Cottus cognatus	-	11.0	22.8	26.1	-	-
	Spoonhead Sculpin	*Cottus ricei*	-	6.0	-	-	-	-
Cyprinidae	Blackchin Shiner	*Notropis heterodon*	-	-	38.0	32.8	-	-
	Blacknose Dace	*Rhinichthys atratulus*	-	19.6	28.6	30.2	-	-
	Bluntnose Minnow	*Pimephales notatus*	26.2	24.1	31.5	29.9	-	-
	Carp	*Cyprinus carpio*	27.3	27.7	34.5	39.0	24	21
	Central Stoneroller	*Campostoma anomalum*	24.8	23.9	31.0	34.3	-	-
	Common Shiner	*Notropis cornutus*	22.0	21.9	30.4	31.2	-	-
	Creek Chub	*Semotilus atromaculatus*	-	24.9	29.1	33.0	-	-
	Emerald Shiner	*Notropis atherinoides*	25.7	19.3	27.4	28.6	24	23.9
	Fallfish	*Semotilus corporalis*	-	22.0	-	-	-	-

Family	Common Name	Scientific Name	Temperature °C					
			OGT	FTP	UILT	CTMax	OS	OE
	Fathead Minnow	*Pimephales promelas*	25.8	26.6	31.3	34.1	19.48	25
	Finescale Dace	*Chrosomus neogaeus*	-	24.1	30.3	32.2	18.5	20
	Golden Shiner	*Notemigonus crysoleucas*	25.0	21.8	32.0	33.4	20.25	20
	Goldfish	*Carassius auratus*	26.6	27.4	34.9	35.8	21.08	16.95
	Longnose Dace	*Rhinichthys cataractae*	-	15.3	-	31.4	11.7	15.6
	Northern Redbelly Dace	*Chrosomus eos*	-	25.3	29.2	29.0	-	-
	Pugnose Shiner	*Notropis anogenus*	-	16.5	-	-	-	-
	Rosyface Shiner	*Notropis rubellus*	25.5	25.3	33.0	33.6	24.3	21.1
	Spotfin Shiner	*Cyprinella spiloptera*	28.9	27.5	36.0	-	-	-
	Spottail Shiner	Notropis hudsonius	27.3	16.6	33.0	33.2	19	20
Cyprinodontidae	Banded Killifish	*Fundulus diaphanus*	-	23.0	31.7	-	23	24.35
	Mummichog	*Fundulus heteroclitus*	24.3	25.0	27.6	39.8	-	-
Esocidae	Grass Pickerel	*Esox americanus vermiculatus*	-	25.7		-	9.45	8.35
	Muskellunge	*Esox masquinongy*	25.1	25.4	32.2	32.0	12.8	13.5
	Northern Pike	*Esox lucius*	23.0	20.7	31.0	-	11.5	12.05
Gadidae	Burbot	*Lota lota*	16.6	13.2	23.3	-	1.15	7.5
Gasterosteidae	Brook Stickleback	*Culaea inconstans*	-	21.3	30.6	-	13.13	18.3
	Ninespine Stickleback	*Pungitius pungitius*	-	16.5	-	-	-	-
	Threespine Stickleback	*Gasterosteus aculeatus*	17.1	12.5	27.2	28.7	12.5	19
Hiodontidae	Mooneye	*Hiodon tergisus*	-	28.0	-	-	-	-
Ictaluridae	Black Bullhead	*Ictalurus melas*	-	-	35.4	37.5	-	-
	Brown Bullhead	*Ameiurus nebulosus*	30.0	26.2	33.4	37.9	21.1	22.8
	Channel Catfish	*Ictalurus punctatus*	29.5	27.3	32.9	36.7	-	-
	Stonecat	*Noturus flavus*	-	15.3	-	29.0	-	-
	Yellow Bullhead	*Ictalurus natalis*	-	28.2	-	36.4	-	-
Lepisosteidae	Longnose Gar	*Lepisosteus osseus*	26.4	27.4	-	-	-	-
	Spotted Gar	*Lepisosteus oculatus*	-	16.0	-	-	-	-
Moronidae	White Bass	*Morone chrysops*	-	27.3	33.5	35.3	15.5	17.45
	White Perch	*Morone americana*	28.5	29.8	36.0	-	17.5	19.95
Percichthyidae	Striped Bass	Morone saxatilis	-	-	28.8	25.9	-	-
Percidae	Eastern Sand Darter	*Ammocrypta pellucida*	-	24.6	-	-	-	-
	Rainbow Darter	*Ethestoma carolineum*	-	19.9	-	32.1	-	-
	Sauger	*Stizostedion canadense*	22.0	19.6	-	-	10.33	13.5
	Walleye	*Stizostedion vitreum*	22.1	22.5	29.7	23.4	7.73	12.2
	Yellow Perch	*Perca flavescens*	25.4	17.6	25.6	35.0	9.13	15
Percopsidae	Trout-Perch	*Percopsis omniscomaycus*	-	13.4	-	22.9	-	-
Petromyzontidae	Sea Lamprey	*Petromyzon marinus*	17.5	10.3	31.4	-	15.35	18.5
Salmonidae	Atlantic Salmon	*Salmo salar*	13.6	15.3	27.6	32.8	-	-
	Bloater	*Coregonus hoyi*	18.6	8.5	26.5	-	-	-
	Brook Trout	*Salvelinus fontinalis*	14.2	14.8	24.9	29.3	10.7	6.1
	Brown Trout	*Salmo trutta*	12.6	15.7	25.0	28.3	7.8	7.5
	Chinook Salmon	*Oncorhynchus tshawytscha*	14.3	13.8	23.5	25.1	-	-
	Chum Salmon	*Oncorhynchus keta*	13.0	14.1		-	-	-
	Coho Salmon	*Oncorhynchus kisutch*	13.6	14.4	21.8	27.6	6.05	7.15
	Cutthroat Trout	*Oncorhynchus clarkii*	16.5	14.9	21.9	28.0	-	-
	Lake Herring, Cisco	*Coregonus artedii*	18.1	12.4	23.9	-	3.3	5.6
	Lake Trout	*Salvelinus namaycush*	10.0	11.8	24.3	-	-	-
	Lake Whitefish	*Coregonus clupeaformis*	14.7	12.7	23.9	-	3.05	4.95
	Pink Salmon	*Oncorhynchus gorbuscha*	15.5	13.0		-	10	7.25
	Rainbow Trout	Oncorhynchus mykiss	15.7	15.5	25.0	22.1	7	8.9
	Round Whitefish	*Proposium cylindraceum*	-	8.3	-	-	3.75	3
	Sockeye Salmon	*Oncorhynchus nerka*	15.0	13.7	21.5	-	8.63	8.25
Sciaenidae	Freshwater Drum	*Aplodinotus grunniens*	22.0	24.6	32.8	34.0	21	23.9
Umbridae	Central Mudminnow	*Umbra limi*	-	-	33.5	-	-	-

Of all the metrics, FTP was the most complete, with information available for 83 of 87 species (Table 2). These data also had the most within-species replication, with a median of 10.5 estimates per species. Forty-seven species had four or more values for FTP, the most among all metrics. The reproduction metrics (OS and OE) had the least amount of data available and the least amount of intra-specific replication, with neither metric having more than three estimates per species. Spawning season data were available for all but one species, American eel (*Anguilla rostrata*), which spawns in the Sargasso Sea (Scott and Crossman 1973). This species was disregarded in any further analyses involving spawning season.

Where sufficient replication was available to evaluate it, intra-specific variation among the estimates for a single metric was relatively similar for the four metrics: standard deviations ranged from 2.3 C° for OGT and CTmax to 3.7 C° for FTP (Table 2). Replication within families was moderately high: six families had five or more species with values for at least one metric (Table 3).

Pair-wise correlation analysis revealed high covariation among metrics (correlation values>0.6; Figure 1). The highest correlation was found between the reproductive metrics, OS and OE, and the growth metrics, FTP and OGT, with Pearson correlation values of 0.8398 and 0.9098, respectively. Metrics FTP and OE exhibited the lowest Pearson correlation (0.6225).

Temperature metrics were also clearly grouped by temperature preference class, reproductive guild, and spawning season with very little overlap. For temperature preference class, OGT, FTP, and ULIT data were well clustered within each class and increased progressively from *cold* to *warm* (Figure 2). All metrics were also distinctly grouped by reproductive guild, with a prominent clustering of low temperature values for guild A.2. Grouping by spawning season was also observed, with metric values clustered at lower temperature values for fall spawners and higher ones for spring spawners (Figure 3). Fall spawners exhibited a narrower range of values for their temperature metrics than spring spawners.

Table 2. *Summary statistics for growth, survival, and reproduction metric data for 87 Ontario freshwater fish species. A dash (-) indicates that no data were found.*

Summary Statistics	Growth		Survival		Reproduction	
	OGT[1]	FTP[2]	UILT[3]	CTMax[4]	OS[5]	OE[6]
Total number of species present	52	83	63	55	48	48
Median number of values present per species	3.5	10.5	9.5	4.5	2.5	2
Total number of species with n≥4 values	7	47	27	11	-	-
Median standard deviation with n≥4 values	2.3	3.7	2.8	2.3	-	-

[1]OGT: Optimum growth temperature [2]FTP: Final temperature preferendum [3]UILT: Upper incipient lethal temperature [4]CTMax: Critical thermal maximum
[5]OS: Optimum spawning temperature [6]OE: Optimum egg development temperature

Table 3. *Mean, minimum, and maximum temperature (°C) values for the growth, survival,and reproduction metrics for taxonomic families (n>5, data available across all metrics).*

Family Name	Temperature (°C)	Growth		Survival		Reproduction	
		OGT[1]	FTP[2]	ULIT[3]	CTMax[4]	OS[5]	OE[6]
Catostomidae	mean	25.3	20.6	28.1	32.7	15.1	16.4
	minimum	25.0	11.1	26.8	30.8	10.0	12.5
	maximum	25.6	23.4	30.9	37.2	17.5	20.5
Centrarchidae	mean	25.5	25.5	34.1	36.5	20.9	22.6
	minimum	19.2	19.1	31.9	32.8	17.0	18.2
	maximum	30.1	30.6	40.0	40.2	26.0	28.0
Cyprinidae	mean	25.9	22.8	31.9	32.6	20.3	20.4
	minimum	22.0	15.3	27.8	28.6	11.7	15.6
	maximum	28.9	27.9	38.0	39.0	24.3	25.0
Ictaluridae	mean	29.8	24.3	33.9	35.5	21.1	22.8
	minimum	29.4	18.6	33.2	29.0	21.1	22.8
	maximum	30.0	28.3	35.4	37.9	21.1	22.8
Percidae	mean	22.1	21.7	29.3	27.1	9.0	12.9
	minimum	22.3	17.8	25.6	23.4	7.7	12.2
	maximum	25.4	24.6	30.5	35.0	10.3	15.0
Salmonidae	mean	14.8	13.0	29.0	27.6	7.4	7.7
	minimum	10.0	8.3	21.9	22.1	3.1	3.0
	maximum	18.6	15.7	31.4	32.8	15.4	18.5

[1]OGT: Optimum growth temperature [2]FTP: Final temperature preferendum [3]UILT: Upper incipient lethal temperature [4]CTMax: Critical thermal maximum

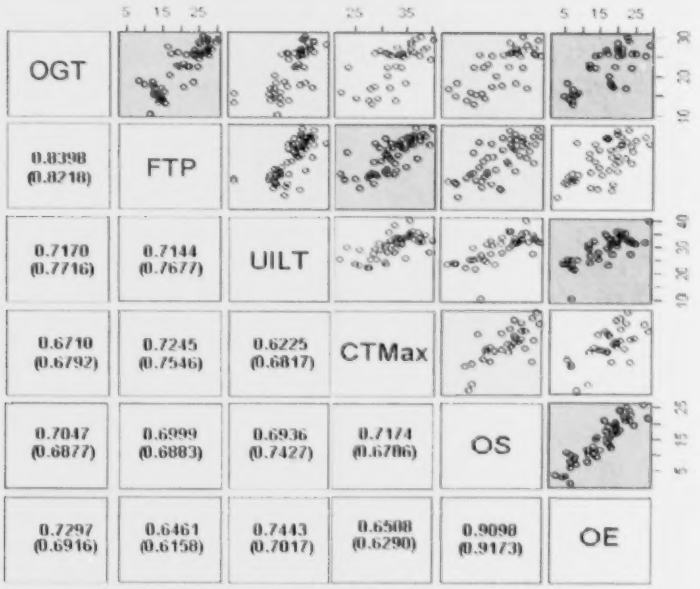

Figure 1. *A scatterplot matrix showing the relationships among growth (optimum growth temperature [OGT] and final temperature preferendum [FTP]), survival (upper incipient letha temperature [UILT] and critical thermal maximum [CTMax]) and reproduction metrics (optimum spawning temperature [OS]and optimum egg development temperature [OE]). Correlation increases with colour intensity (dark gray>0.72, medium gray 0.72-0.69, light gray<0.69). For each relationship, Pearson and Spearman (in parentheses) correlation coefficients are also prorided. All correlations were statistically significant (p<0.01).*

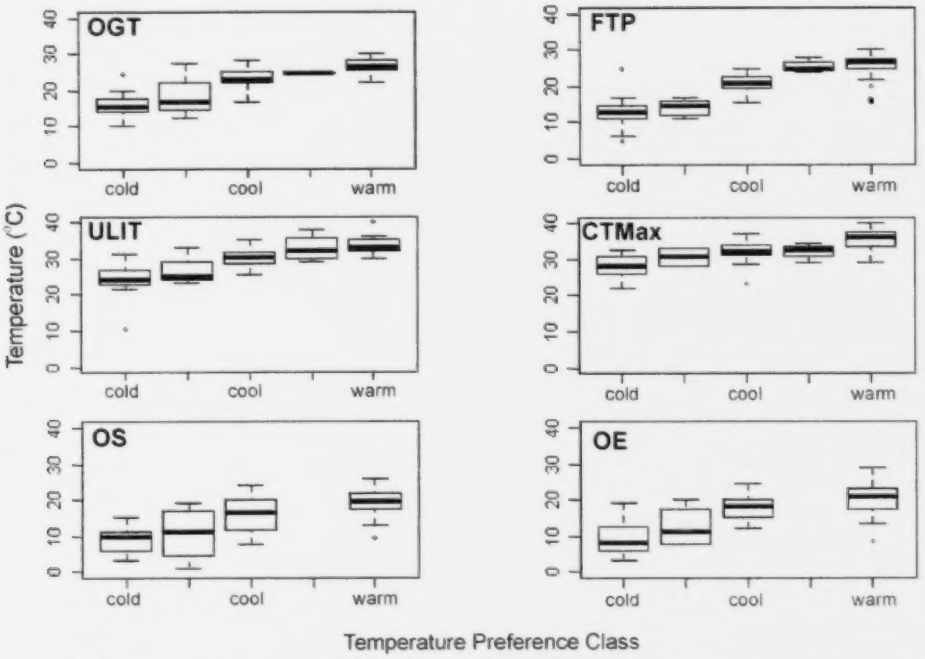

Figure 2. *Growth (OGT and FTP), survival (UILT and CTMax), and reproduction (OS and OE) metric distributions across five temperature preference classes: cold (<19°C, n=24), cold/cool (n=4), cool (19-25°C, n=24), cool/warm (n=6) and warm (>25°C, n=28).*

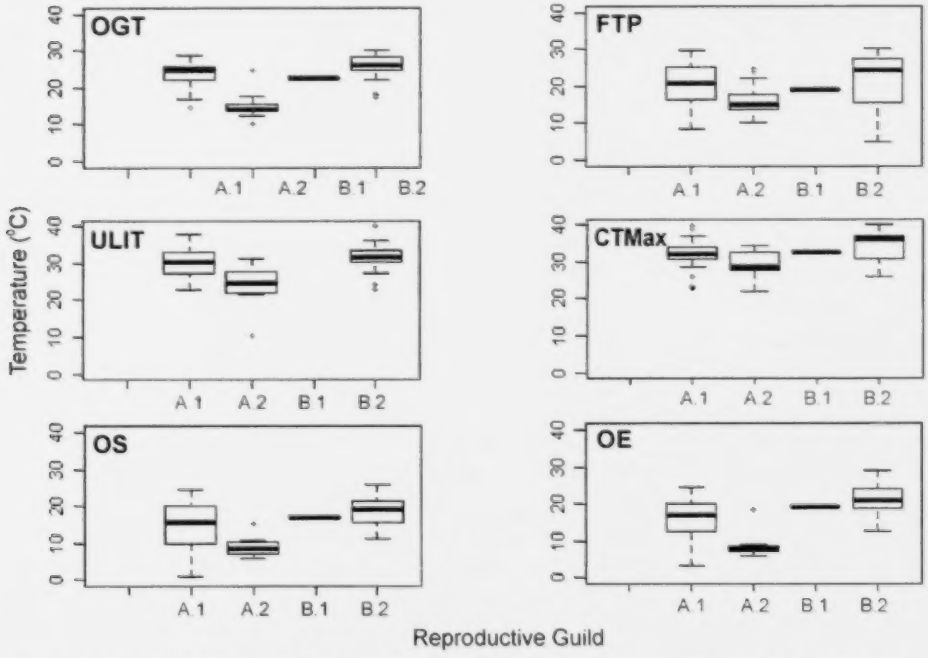

Figure 3. *Growth (OGT and FTP), survival (UIT and CTMax), and reproduction (OS and OE) metric distributions across four reproductive guild categories; A.1 (broadcast spawners pelagophils, n=47), A.2 (broadcast spawners lithiophils, n=16), B.1 (brood hiders lithiophils, n=1) and B.2 (brood hiders aeropsammophils, n=23).*

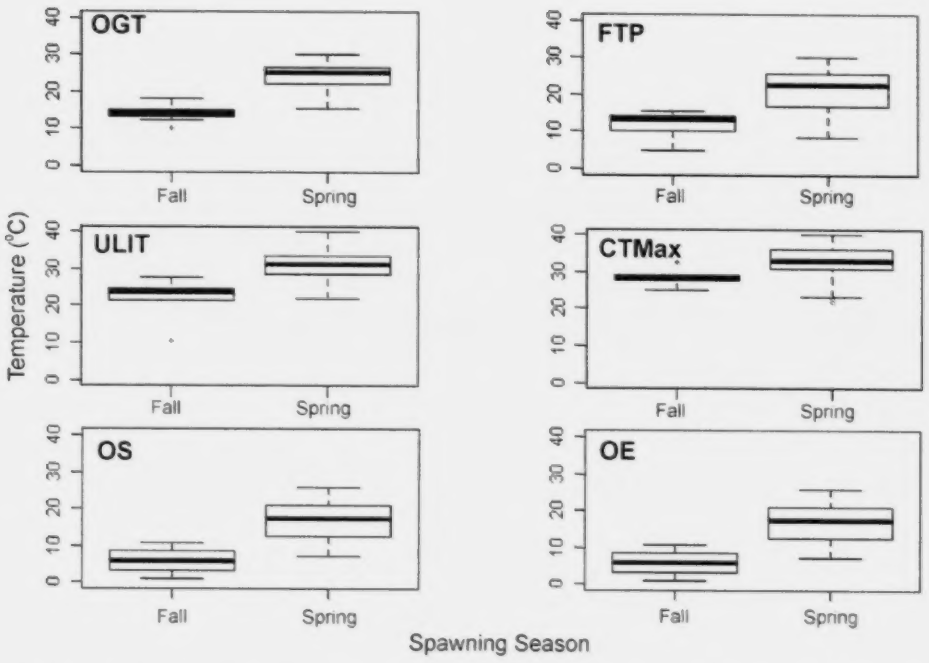

Figure 4. *Growth (OGT and FTP), survival (ULIT and CTMax), and reproduction (OS and OE) metric distributions for two spawning seasons; fall (September to early November, n=17); spring (April to late June, n=70).*

Discussion

The significant positive correlations observed between all metrics confirm (for a larger sample size) the results of similar studies by Jobling (1981) and Beitinger et al. (2000). In addition, we examined reproductive metrics along with growth and survival metrics and found that metrics associated with all three processes were positively correlated. These strong correlations suggest that growth, survival and reproductive metrics are interdependent across species and this interdependence provides the empirical basis for estimating the value of an unknown metric from the value of a known metric.

The strong associations between growth, survival, and reproduction metrics on the one hand and three life history characteristics (i.e., temperature preference class, reproductive guild and spawning season) on the other, also indicate that a species' life history characteristics shape and are shaped by its thermal preferences and limits. These results also indicate that the temperature preference classification system developed by Coker et al. (2000), with limited metric data, holds true for a larger data set. In addition, the results point to the possibility of a thermal association with the seasonal timing of spawning, and with reproductive behaviour itself, as categorized by Balon's (1975, 1981) reproductive guild concept.

Our compilation of estimates for six thermal metrics, reveals a number of biases in the thermal ecology literature for Canadian freshwater fish. For example:

- Numerous FTP estimates for many species contrast with few OS and OE estimates, suggesting a need for further work to characterize inter-specific differences in the thermal ecology of reproduction.
- Most metric estimates focus on a single life stage (young-of-year, juvenile, or adult), suggesting the need for further work to evaluate the intra-specific stability of thermal metrics across life stages. This is re-inforced by, for example, the compilation of metric estimates by Wismer and Christie (1987) in which adult growth metric estimates can differ by more than ±2C° from those for younger life stages of the same species.
- Many metric estimates are derived from test fish acclimated to a single temperature. Given the sensitivity of growth and survival metrics to acclimation temperature, estimates based on only one acclimation temperature may suggest a narrower temperature range for survival and growth than is actually the case (Beitinger et al. 2000).

Potential Applications

Potential applications for growth temperature, survival, and reproduction metrics are numerous. Some examples for each are:

Growth Metrics

- Values for the optimum growth and final temperature preferendum can be used to establish the thermal niche habitable by a particular fish species (Magnuson et al. 1979, Christie and Regier 1988). Combined with lake volume and temperature profile data, the thermal niche can then be used to determine the productive capacity for the population of a particular species, resident in a given lake (Christie and Regier 1988).
- Given lake temperature data, and values for optimum growth and final temperature preferendum, species-specific thermal habitat dynamics can be derived and used to predict population performance and suitable habitat area (Chu et al. 2004).

Survival Metrics

- Values for the upper incipient lethal and critical thermal maximum temperatures can be used to identify the potential southern limit of the zoogeographical distribution of a species (Meisner 1990a).
- Survival metrics coupled with species diversity in a given lake can provide a basis for regulating heated discharge from power plants (Coutant and Talmadge 1977).
- Seasonal temperature maxima exhibited by streams during spring and summer can be detrimental to fish species limited by low survival threshold temperatures. Survival metrics can be used to identify affected species and determine thermal avoidance migration patterns (Meisner 1990b).

Reproduction Metrics

- Species-specific spawning and egg development temperatures can be used to identify spawning sites (Rejwan et al. 1997).
- Coupled with lake temperature data, reproduction metrics can be used to determine species specific spawning times (Shuter and Post 1990).

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Appendix

Table A1. *Optimum growth temperature (OGT), final temperature preferendum (FTP), upper incipient lethal temperature (UILT), and critical thermal maximum (CTMax) data for 87 Canadian freshwater species. Species are arranged alphabetically within families. All temperatures are recorded in °C. Asterisks (**) indicate temperature values not included in statistical analyses due to procedural discrepancies. References are provided in an Appendix reference list that follows the tables.*

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
Acsipenseridae									
Lake Sturgeon	*Ascipenser fulvescens*			11.0	E(2009)				
Amiidae									
Bowfin	*Amia calva*			30.5	WC(1987)			37.0	WC(1987)
				28.0-32.0	E(2009)				
Anguillidae									
American Eel	*Anguilla rostrata*	25.0	WC (1987)	16.7	WC(1987)				
				20.5	WC(1987)				
				24.9	WG(1991)				
				16.0-19.0	E(2009)				
Catostomidae									
Bigmouth Buffalo	*Ictiobus cyprinellus*			6.0-24.0	WC(1987)				
				18.0-26.0	WC(1987)				
				22.0-23.0	WC(1987)				
Longnose Sucker	*Catostomus catostomus*			8.0-17.0	E(2009)	26.5	WC(1987)		
				11-11.6	WC(1987)	27.0	WC(1987)		
				8.0-17.0	WC(1987)				
				8.0	WC(1987)				
Northern Hog Sucker	*Hypentelium nigricans*	25.8	J(1981)	26.0	J(1981)	30-34	R(2000)	30.9	S(1979)
		25.3	J(1981)	26.6	E(2009)	33.0	WC(1987)		
				29.2	WC(1987)	27.0	WC(1987)		
				25.2	WC(1987)	30.0	WC(1987)		
				28.6	J(1998)	19.0-27.0	E(2009)		
				26-27	S(1974)	34.0	WC(1987)		
Quillback	*Carpoides cyprinus*			22.1	WC(1987)			37.2	S(1979)
				26.3	WC(1987)				
				10.0-16.0	WC(1987)				
Spotted Sucker	*Minytrema melanops*			25.0-27.0	WC(1987)	31.0	WC (1987)		

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				16.0-19.0	WC(1987)				
White Sucker	*Catostomus commersoni*	27.0	J(1981)	24.0	J(1981)	26.3	S(1979)	31.6	WC (1987)
		24.0	WC(1987)	18.3-26.7	D(1991)	27.7	S(1979)		
				22.4	WC(1987)	29.3	S(1979)		
				14.1-18.3	WC(1987)				
				23.9	WC(1987)				
				25-27	WC(1987)				
				16.0-49.0	WC(1987)				
				19.0-21.0	WC(1987)				
				24.1	WC(1987)				
				26.7	WC(1987)				
				14.4	WC(1987)				
				22-26	E(2009)				
				27.1	J(1998)				
Centrarchidae									
Black Crappie	*Poxomis negromaculatus*	9.0-17.0	WC(1987)	27.8-29.8	J(1998)	34.0	WC (1987)	34.9	S(1979)
		22-25	WC(1987)	24.0-29.8	J(1998)	32.5	WC (1987)		
				20.5	WC(1987)				
				21.0	WC(1987)				
				21.7	WC(1987)				
				22.2	WC(1987)				
				24.0	WC(1987)				
				24.6	WC(1987)				
				21.3	WC(1987)				
				21.0-25.0	E(2009)				
Bluegill	*Lepomis macrochirus*	30.1	J(1981)	32.0	J(1981)	31.0	WC(1987)	37.8	S(1979)
		31.0	J(1981)	31.2	J(1981)	32.0	WC(1987)	40.0	S(1979)
		29-30	J(1981)	31.0	J(1981)	33.0	WC(1987)	43.4	S(1979)
		30.0	WC(1987)	32.0	J(1981)	34.0	WC(1987)	38.3	S(1979)
		24-27	WC(1987)	30.9	J(1981)	35.5	WC(1987)	41.5	WC(1987)
		27.0	WC(1987)	30.7	J(1998)	30.7	S(1979)		
		31.2	WC(1987)	31.4	J(1998)	31.7	S(1979)		
				30.9-32.3	D (1991)	33.8	S(1979)		
				24.6-32.0	D(1991)	28.5	S(1979)		
				27.4	WC(1987)				
				24.0-30.0	E(2009)				

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
Green Sunfish	*Lepomis cyanellus*	28.0	WC(1987)	30.3	J(1998)	40.0	WG(1991)	36.0	WC(1987)
				15.9	WC(1987)				
				22.7	WC(1987)				
				30.6	WC(1987)				
				26.8	WC(1987)				
				27.0-31.0	E(2009)				
Largemouth Bass	*Micropterus salmoides*	27.5	J(1981)	30.0-32.0	J(1981)	29.0	WC(1987)	36.7	S(1979)
		27.0	J(1981)	30.0	J(1981)	30.0	WC(1987)	40.1	S(1979)
		25.0	J(1981)	30.2	J(1981)	32.5	S(1979)		
		26.0-28.0	J(1981)	28.5	J(1981)	34.5	S(1979)		
				32.2	J(1998)	36.4	S(1979)		
				28.5-32.0	J(1981)	28.9	S(1979)		
				26.6-32.0	J(1981)				
				29.0	J(1981)				
				28.0	WC(1987)				
				27.0-32.0	WC(1987)				
				29.5	WC(1987)				
				27.1	WC(1987)				
				27.0	WC(1987)				
				30.4	WC(1987)				
				21.3	WC(1987)				
				27.0	WC(1987)				
				26.0-30.0	E(2009)				
Pumpkinseed	*Lepomis gibbous*	25.0	WC (1987)	31.0	J(1981)	28.0	S(1979)	37.6	S(1979)
				26.0	J(1981)	30.0	S(1979)		
				31.3	J(1998)	34.5	S(1979)		
				26.0-32.0	D (1991)	27.7-28.3	WC(1987)		
				26.0	J(1981)	32.3-32.9	WC(1987)		
				28.5	WC(1987)	35.2-35.3	WC(1987)		
				31.7	WC(1987)	28.5	WC(1987)		
				31.5	WC(1987)	31.6	WC(1987)		
				28.4	WC(1987)	31.9	WC(1987)		
				22.9	WC(1987)	33.5	WC(1987)		
				25.3	WC(1987)	31.7	WC(1987)		
				26.9	WC(1987)	37.0	WC(1987)		
				27.0	WC(1987)	24.5	WC(1987)		

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				23.2	WC(1987)	36.6	WC(1987)		
				25.5	WC(1987)	34.8	WC(1987)		
				28.8	WC(1987)				
				29.5	WC(1987)				
				25.6	WC(1987)				
				28.1	WC(1987)				
				30.3	WC(1987)				
				24.2	WC(1987)				
				27.7	WC(1987)				
				22.0-30.0	E(2009)				
Rock Bass	*Ambloplites rupestris*	27.7	J(1981)	28.0	J(1981)	35.0	WC(1987)	36.0	S(1979)
		29.0	J(1981)	30.6	J(1998)	32.8	S(1979)		
				21-30	D(1991)				
				29.0	J(1981)				
				21.3	WC(1987)				
				20.7	WC(1987)				
				27.0-27.8	WC(1987)				
				26.8-28.3	WC(1987)				
				26.2	WC(1987)				
				28.8	WC(1987)				
				21.6	WC(1987)				
				20.5	WC(1987)				
				22.8	WC(1987)				
				27.5	WC(1987)				
				27.4	WC(1987)				
				30.0	WC(1987)				
				19.6	WC(1987)				
				20.2	WC(1987)				
				18.7	WC(1987)				
				21.0-26.0	E(2009)				
Smallmouth bass	*Micropterus dolomieui*	26.0	J(1981)	28.0	J(1981)	37.0	WC(1987)	36.3	S(1979)
				31.3	J(1981)	35.0	WC(1987)		
				30.3	J(1981)				
				21.3-31.3	D(1991)				
				12.0-13.0	WC(1987)				
				15.0-16.0	WC(1987)				

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				30.0	WC(1987)				
				21.0-23.0	WC(1987)				
				30.0-31.0	WC(1987)				
				26.6	WC(1987)				
				20.0	WC(1987)				
				20-26	E(2009)				
				28.5	J(1981)				
White Crappie	*Poxomis annularis*	24.0	B(2007)	19.8	WC(1987)			32.8	S(1979)
		18-24	HA(1996)	18.3	WC(1987)				
				10.4	WC(1987)				
				19.4	WC(1987)				
				23.0	WC(1987)				
				23-24	WC(1987)				
				19.4	E(2009)				
Clupeidae									
Alewife	*Alosa pseudoharengus*	20.1	GLFC(2009)	16-21	E(2009)	28.5	WC(1987)	31.0-34.0	WC(1987)
				19.6	WC(1987)	8.5	WC(1987)	28.6	WC(1987)
				12.0	WC(1987)	7.0	WC(1987)	30.6	WC(1987)
				21.0	WC(1987)	31.0-34.0	WC(1987)	32.6	WC(1987)
				19.0	WC(1987)	2.0	WC(1987)	32.0	WG(1991)
				16.0	WC(1987)	22.8	WC(1987)		
				11.0	WC(1987)	33.3	WC(1987)		
				11.0-14.0	WC(1987)	31.4	WC(1987)		
				13.0-16.0	WC(1987)	23.2	WC(1987)		
				25.0	WG(1991)	29.7	GLFC(2009)		
						23.5	S(1979)		
						24.5	S(1979)		
						33.0	WG(1991)		
						23.0	WG(1991)		
Gizzard Shad	*Dorosoma cependianum*	16.0-18.0	WC (1987)	19.0	WC(1987)	34.0	S(1979)	31.7	WC(1987)
				20.5	WC(1987)	36.0	S(1979)		
				23.0	WC(1987)	36.5	S(1979)		
				26.0-34.0	WC(1987)				
				10.0-12.0	WC(1987)				
				12.0	WC(1987)				
				4.0-10.0	WC(1987)				

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				28.5-31.0	WC(1987)				
Cottidae									
Deepwater Sculpin	*Myoxocephalus thompsoni*			5.0	WC(1987)				
				2.0-10.0	WC(1987)				
				2.0-6.0	WC(1987)				
Fourhorn Sculpin	*Myoxocephalus quadricornis*			1.0-9.0	E(2009)				
Mottled Sculpin	*Cottus biardii*			16.5	WC(1987)	24.3	Wh(1999)	30.9	S(1979)
				16.7	WC(1987)				
				13.0-18.0	E(2009)				
Slimy Sculpin	*Cottus cognatus*			6.0-8.0	WC(1987)	26.5	WC(1987)	22.7	WC(1987)
				4.0-6.0	WC(1987)	18.5	WC(1987)	24.8	WC(1987)
				9.0	WC(1987)	22.5	WC(1987)	26.3	WC(1987)
				12.0	WC(1987)	23.5	WC(1987)	29.4	WC(1987)
				10.0	WC(1987)			24.0	WC(1987)
				13.0	WC(1987)			25.1	WC(1987)
				9.0-14.0	E(2009)			27.3	WC(1987)
				10.7	WG(1991)			29.4	WC(1987)
Spoonhead Sculpin	*Cottus ricei*			4.0-8.0	E(2009)				
Cyprinidae									
Blackchin Shiner	*Notropis heterodon*					38.0	WC(1987)	32.8	WC(1987)
Blacknose Dace	*Rhinichthys atratulus*			19.6	WG(1991)	25.0	WC(1987)	29.5	WC(1987)
						27.0	WC(1987)	29.3	WC(1987)
						29.3	WC(1987)	31.9	WC(1987)
						26.5	WC(1987)		
						28.8	WC(1987)		
						29.6	WC(1987)		
						31.7	WC(1987)		
						29.9	WC(1987)		
						30.0	WC(1987)		
Bluntnose Minnow	*Pimephales notatus*	27.4	J(1981)	29.0	J(1981)	32.0	WC(1987)	27.8	S(1979)
		24.0	J(1981)	28.1	J(1981)	28.3	WC(1987)	31.9	S(1979)
		27.2	J(1981)	20-27.2	S(1974)	26.0	S(1979)		
				15.7	S(1979)	28-28.3	S(1979)		
				17.2	S(1979)	30.6	S(1979)		
				20.5	S(1979)	31.7-32.0	S(1979)		

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				20.4	S(1979)	33.3	S(1979)		
				21.5	S(1979)	34.8	S(1979)		
				22.8	S(1979)	31.7	WC(1987)		
				25.7	S(1979)	38.0	WC (1987)		
				28.9	S(1979)				
				29.0	S(1979)				
				28.4	S(1979)				
				21.0	S(1979)				
				26.3	E(2009)				
				29.0	WC(1987)				
Carp	*Cyprinus carpio*	30.0	J(1981)	32.6	J(1998)	31.0-34.0	S(1979)	39.0	S(1979)
		32.0	J(1981)	32.0	J(1981)	35.7	S(1979)		
		27.0	WC(1987)	31.5	J(1981)	35.4	S(1979)		
		20.0-25.0	WC(1987)	29.3-31.9	D(1991)	31-34	S(1979)		
		23.0-27.0	WC(1987)	28.2-31.9	D(1991)	35.7	S(1979)		
				29.0	J(1981)				
				27.4	WC(1987)				
				29.7	WC(1987)				
				25.0-30.0	WC(1987)				
				26.0-34.0	WC(1987)				
				16.0-20.0	WC(1987)				
				5.0-16.0	WC(1987)				
				28-32	E(2009)				
Central Stoneroller	*Campostoma anomalum*	26.6	J(1981)	29.0	J(1998)	31.0	WC (1987)	28.8	B(2000)
		23.0	J(1981)	26.6	J(1998)			35.8	B(2000)
				28.6	J(1981)			37.7	B(2000)
				26.2	J(1981)			37.2	B(2000)
				29.0	WC(1987)			31.8	B(2000)
				28.5	WC(1987)				
				26.2	WC(1987)				
				20-27	S(1974)				
				13.4	WC(1987)				
				15.2	WC(1987)				
				20.7	WC(1987)				

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				21.7	WC(1987)				
				22.3	WC(1987)				
				23.6	WC(1987)				
				25.3	WC(1987)				
				27.5	WG(1991)				
Common Shiner	*Notropis cornutus*	22.0	NJFW(2009)	21.9	E(2009)	32.0	S(1979)	30.6	S(1979)
						26.7-27.0	WC(1987)	31.9	S(1979)
						28.6-29.0	WC(1987)	31.0	WG(1991)
						30.3	WC(1987)		
						31.0-32.3	WC(1987)		
						33.5	WC(1987)		
						29.0	WC(1987)		
						30.5	WC(1987)		
						26.7	WC(1987)		
						28.6	WC(1987)		
						30.3	WC(1987)		
						31.0	WC(1987)		
						30.6	WC(1987)		
						31.1	WC(1987)		
Creek Chub	*Semotilus atromaculatus*			28.0	E(2009)	24.7	WC(1987)	30.3	WC(1987)
				21.8	WG(1991)	27.0	WC(1987)	35.7	B(2000)
						30.1-30.5	WC (1987)		
						30.0	WC (1987)		
						31.8	WC (1987)		
						32.1	WC (1987)		
						32.6	WC (1987)		
						24.7	WC (1987)		
						27.3	WC (1987)		
						30.3	WG(1991)		
						29.3	WC (1987)		
Emerald Shiner	*Notropis atherinoides*	27.0	J(1981)	27.8	J(1981)	23.2	S(1979)	28.6	WC (1987)
		24-28.9	WC (1987)	25.1	J(1981)	26.7	S(1979)		
				8.3	WC (1987)	28.9	S(1979)		
				9.0-23.0	E(2009)	30.7	S(1979)		

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
Fallfish	*Semotilus corporalis*			22.0	E(2009)				
Fathead Minnow	*Pimephales promelas*	26.0	J(1981)	26.2	J(1998)	33.2	WC (1987)	32.4	B(2000)
		25.5	J(1981)	23.4	J(1981)	28.0	WC (1987)	34.0	B(2000)
				28.5	J(1981)	32.3	WC (1987)	33.2	B(2000)
				29.0	J(1981)	33.0	WC (1987)	35.1	B(2000)
				26.6	J(1981)	28.2	WC (1987)	34.8	B(2000)
				23.0-29.0	E(2009)	31.7	WC (1987)	34.9	B(2000)
								33.1	B(2000)
								36.8	B(2000)
								36.2	B(2000)
								36.7	B(2000)
								34.4	B(2000)
								28.6	B(2000)
								30.7	B(2000)
								36.4	B(2000)
								40.4	B(2000)
								25.9	B(2000)
								36.5	B(2000)
Finescale Dace	*Chrosomus neogaeus*			24.1	WG(1991)	27.0	WC (1987)	32.2	WG(1991)
						28.0	WC (1987)		
						31.0	WC (1987)		
						30.3	WC (1987)		
						32.2	WC (1987)		
						31.3	WC (1987)		
						32.2	WC (1987)		
Golden Shiner	*Notemigonus crysoleucas*	26.0	M(2008)	16.8	WC (1987)	29.3	WC (1987)	30.5	WC (1987)
		23.9	M(2008)	23.7	WC (1987)	30.5	WC (1987)	36.4	B(2000)
				22.3	WC (1987)	31.8	WC (1987)	33.4	B(2000)
				21.0	WC (1987)	33.2	WC (1987)		
				23.9-28.9	WC (1987)	34.7	WC (1987)		
				24.0	WC (1987)	30.3	WC (1987)		
				16.8-23.7	CSJ(1984)	33.5	WC (1987)		

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				17.0-24.0	E(2009)	33.4	WC (1987)		
						32.8	WC (1987)		
						31.6	WC (1987)		
						30.4	WC (1987)		
						31-31.6	WC (1987)		
						32.7	WC (1987)		
						27.0-35.0	WC (1987)		
Goldfish	*Carassius auratus*	25.0	J(1981)	30.0	J(1981)	40.0	WC (1987)	36.6	S(1979)
		28.1	WC (1987)	28.0	J(1981)	29-38.6	WC (1987)	35.0	S(1979)
				27.0	WC (1987)	29.9-41	WC (1987)		
				24.0	WC (1987)	29.0	S(1979)		
				27.9	WC (1987)	30.8	S(1979)		
						32.8	S(1979)		
						34.8	S(1979)		
						36.6	S(1979)		
						38.6	S(1979)		
						29.9	S(1979)		
						31.5	S(1979)		
						33.0	S(1979)		
						35.0	S(1979)		
						37.5	S(1979)		
						39.0	S(1979)		
						41.0	S(1979)		
Longnose Dace	*Rhinichthys cataractae*			10.0-19.7	WC (1987)			31.4	S(1979)
				8.0-14.0	WC (1987)				
				10.0-22.7	WC (1987)				
				13.0-21.0	E(2009)				
				7.2-14.7	WC (1987)				
				20.9	WG(1991)				
				10.0-22.9	WG(1991)				

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
Northern Redbelly Dace	*Chrosomus eos*			25.3	WG(1991)	33.1	WC (1987)	29.0	WC (1987)
						28.0	WC (1987)		
						21.5	WC (1987)		
						26.5	WC (1987)		
						30.0	WC (1987)		
						31.0	WC (1987)		
						28.0	WC (1987)		
						31.5	WC (1987)		
						29.5	WC (1987)		
						32.7	WC (1987)		
Pugnose Shiner	*Notropis anogenus*			15.0-18.0	WC (1987)				
Rosyface Shiner	*Notropis rubellus*	25.7	J(1981)	27.6	J(1998)	33.0	WC (1987)	31.8	B(2000)
		25.3	J(1981)	26.1	J(1998)			35.3	B(2000)
				26.8	WC (1987)				
				20.8	WC (1987)				
				21.7	WC (1987)				
				22.2	WC (1987)				
				22.5	WC (1987)				
				25.8	WC (1987)				
				28.1	WC (1987)				
				28.0	WC (1987)				
				27.7	WC (1987)				
				26.0	WC (1987)				
Spotfin Shiner	*Cyprinella spiloptera*	28.6	J(1981)	31.0	J(1998)	36.0	WC (1987)		
		29.2	J(1981)	29.5	WC (1987)				
				29.4	WC (1987)				
				21.4	WC (1987)				
				21.8	WC (1987)				
				24.1	WC (1987)				
				26.4	WC (1987)				
				27.3	WC (1987)				

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				30.6	WC (1987)				
				31.8	WC (1987)				
				29.2	WC (1987)				
Spottail Shiner	*Notropis hudsonius*	27.3	WG(1991)	10.2**	WC (1987)	30.6	WC (1987)	32.80	WC (1987)
				17.0-20.0	WC (1987)	31.1	WC (1987)	33.50	WG(1991)
				19.0-20.0	WC (1987)	35.0	WC (1987)		
				17.0-18.0	WC (1987)	35.2	WG(1991)		
				13.0-22.0	E(2009)				
Esocidae									
Grass Pickerel	*Esox americanus vermiculatus*			26.0	WC(1987)				
				25.5	WC(1987)				
				25.6	WC(1987)				
Muskellunge	*Esox masquinongy*	24.0	J(1981)	24.0	J(1981)	32.2	SC(1973)	28.8	S(1979)
		26.6	J(1981)	25.1	J(1981)			31.9	S(1979)
		25.6	GLFC(2009)	22.0-26.0	E(2009)			34.5	S(1979)
								29.9-35.6	S(1979)
Northern Pike	*Exos lucius*	26.0	J(1981)	23.0-24.0	J(1981)	32.0	WC (1987)		
		19.0-21.0	J(1981)	19.0-20.0	D (1991)	31.6-31.7	WC (1987)		
				17.0-21.0	E(2009)	34.0	WC (1987)		
						28.4	WC (1987)		
						30.8	S(1979)		
						29.4	SC(1973)		
Cyprinodontidae									
Banded Killifish	*Fundulus diaphanus*			19.3	WC (1987)	27.50	WC (1987)		
				21.0	E(2009)	38.30	WC (1987)		
				28.6	M (1980)	34.50	WC (1987)		
						26.50	WC (1987)		
Mummichog	*Fundulus heteroclitus*	24.3	J(1981)	25.0	J(1981)	18.6-36.3	GCYK (1972)	34.3	B(2000)
								36.2	B(2000)
								41.0	B(2000)
								42.4	B(2000)
								43.1	B(2000)

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
								44.1	B(2000)
								32.2	B(2000)
								36.2	B(2000)
								38.5	B(2000)
								39.0	B(2000)
								40.5	B(2000)
								42.4	B(2000)
								43.1	B(2000)
								43.6	B(2000)
Gadidae									
Burbot	*Lota lota*	15.6-18.3	WC (1987)	21.2	WC (1987)	23.3	WC (1987)		
				11.4	WC(1987)				
				8.0-17.0	WC(1987)				
				6.0-11.0	WC(1987)				
				7.0-18.0	E(2009)				
Gasterosteidae									
Brook Stickleback	*Culaea inconstans*			21.3	E(2009)	30.6	WC (1987)		
Ninespine stickleback	*Pungitius pungitius*			17.0-24.0	WC(1987)				
				5.0-6.0**	WC(1987)				
				9.0-16.0	E(2009)				
				13.0-14.0**	WC(1987)				
Threespine Stickleback	*Gasterosteus aculeatus*	12.8	J(1981)	7.5-10.0	J(1981)	28.5	WC (1987)	28.7	B(2000)
		19.3	J(1981)	16.0	J(1981)	25.8	WC (1987)		
		19.1	J(1981)	4.0-8.0**	WC(1987)				
				10.0	WC(1987)				
				9.0-12.0	E(2009)				
				16.0-18.0	J(1981)				
Hiodontidae									
Mooneye	*Hiodon tergisus*			27.0-29.0	E(2009)				
Ictaluridae									
Black Bullhead	*Ictalurus melas*					35.7	WC (1987)	37.5	WC (1987)
						35.0	S(1979)		

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
Brown Bullhead	*Ameiurus nebulosus*	32.0	WC (1987)	27.3-31.0	D(1991)	36.1	WC (1987)	37.80	S(1979)
		28.2	J(1981)	11.9**	WC(1987)	28.6-29	WC (1987)	38.00	WC (1987)
		29.9	J(1981)	23.5	WC (1987)	30-30.2	WC (1987)		
				24.9	WC (1987)	33-33.4	WC (1987)		
				23.6	WC (1987)	35.5	WC (1987)		
				29.0-31.0	WC (1987)	36.5-37	WC (1987)		
				27.3	WC (1987)	37.5	WC (1987)		
				26.0	WC (1987)	37.2	WC (1987)		
				26-30	E(2009)	29.0	WC (1987)		
				10.9**	WC (1987)	32.3	WC (1987)		
				22.4	WC (1987)	33.7	WC (1987)		
						34.7	WC (1987)		
						29.9	WC (1987)		
						31.5	WC (1987)		
						33.0	WC (1987)		
						35.0	WC (1987)		
						39.0	WC (1987)		
						41.0	WC (1987)		
						29.1-32.6	WC (1987)		
						33.2-35.5	WC (1987)		
						32.9	WC (1987)		
						27.8	WC (1987)		
						31.0	WC (1987)		
						32.5	WC (1987)		
						33.8	WC (1987)		
						34.8	WC (1987)		
						28.0	WC (1987)		
						36.5	J(1981)		
Channel Catfish	*Ictalurus punctatus*	29.0	J(1981)	30.5	J(1981)	30.3	WC (1987)	34.5	S(1979)
		30.0	J(1981)	30.0	WC(1987)	32.8	WC (1987)	34.2	S(1979)
		28.0-30.0	J(1981)	25.2	WC (1987)	33.5	WC (1987)	35.5	S(1979)

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				25.3	WC (1987)	35.0	WC (1987)	37.5	S(1979)
				26.6-27.2	S(1974)	30.4	WC (1987)	39.2	S(1979)
				32.0	WC (1987)	32.8	WC (1987)	41.0	S(1979)
				18.9	WC (1987)	35.0	WC (1987)	38.0	S(1979)
				20.4	WC (1987)	32.8	WC (1987)	33.5	WC (1987)
				19.9	WC (1987)				
				21.7	WC (1987)				
				22.9	WC (1987)				
				26.1	WC (1987)				
				29.4	WC (1987)				
				29.5	WC (1987)				
				17.0	WC (1987)				
				21.0	WC (1987)				
				22.0	WC (1987)				
				28.0	WC (1987)				
				26.0	WC (1987)				
				15.2**	WC (1987)				
				27-31	E(2009)				
				30.3	S(1979)				
				32.8	S(1979)				
				33.5	S(1979)				
				36.6	S(1979)				
				37.3	S(1979)				
				37.8	S(1979)				
Stonecat	*Noturus flavus*			5.5	WC(1987)			29.0	S(1979)
				25.1	WC(1987)				
Yellow Bullhead	*Ictalurus natalis*			28.3	WC(1987)			36.4	S(1979)
				28.8	WC(1987)				
				27.6	WC(1987)				
Lepisosteidae									
Longnose Gar	*Lepisosteus osseus*	26.4	WC (1987)	30.0-31.8	WC (1987)				
				25.3	WC (1987)				
				33.1	WC (1987)				

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				30.0-34.0	WC (1987)				
				24.0-28.0	WC (1987)				
				12.0-16.0	WC (1987)				
				33.0-35.0	WC (1987)				
				34.0	WC (1987)				
Spotted Gar	*Lepisosteus oculatus*			15.0-17.0	WC (1987)				
Moronidae									
White Bass	*Morone chrysops*			29.4-34.4	D(1991)	33.5	S(1979)	35.3	S(1979)
				12.0-17.0	WC (1987)				
				28-30	WC (1987)				
				16.0-17.0	WC (1987)				
				29.0	WC (1987)				
				33.9-34.3	WC (1987)				
				30.0-34.0	WC (1987)				
				27.8	WC (1987)				
				28.0-32.0	E(2009)				
				27.8	WG(1991)				
White Perch	*Morone americana*	28.5	WC (1987)	29.8	WG(1991)	36.0	WG(1991)		
				26.0-30.0	E(2009)				
Percichthyidae									
Striped Bass	*Morone saxatilis*					24.4	C(2006)	25.3	C(2006)
						27.2	C(2006)	26.0	C(2006)
						29.7	C(2006)	26.5	C(2006)
						31.1	C(2006)		
						31.8	C(2006)		
						33.9	C(2006)		
Percidae									
Eastern Sand Darter	*Ammocrypta pellucida*	24.0	WC (1987)						
		25.0	WC (1987)						
		24.0-25.5	E(2009)						
Rainbow Darter	*Ethestoma carolineum*			19.8	E(2009)			32.1	WC (1987)
				20.0	WC (1987)				
Sauger	*Stizostedion canadense*	22.0	J(1981)	22.6	J(1981)				
				21.3	J(1981)				

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				27.0-29.0	WC (1987)				
				14-21	WC (1987)				
				8.0-11.0	WC (1987)				
				26-28	WC (1987)				
				7.2	WC (1987)				
				21.1	WC (1987)				
				20.0	WC (1987)				
				20.0-24.0	E(2009)				
Walleye	*Stizostedion vitreum*	22.1	J(1981)	20.6-32.2	D(1991)	28.9	WC (1987)	23.4	WC (1987)
				23.0	J(1981)	31.0	WC (1987)		
				22.0	WC (1987)	27.0-31.6	S(1979)		
				20.0	WC (1987)	30.5	WC (1987)		
				19.0-23.0	E(2009)				
Yellow Perch	*Perca flavescens*	23.0	J(1981)	24.2	J(1981)	21.0	WC (1987)	35.0	WC(1987)
		28.0	J(1981)	20.1	J(1981)	25.0	S(1979)		
		23.0-24.0	J(1981)	23.3	J(1981)	28.0	WC (1987)		
		26.0-30.0	WC (1987)	23.0	J(1981)	32.3	WC (1987)		
			WC (1987)	21.4	J(1981)	30.9	WC (1987)		
				20.2	J(1981)	21.3	S(1979)		
				18.0-21.1	D(1991)	27.7	S(1979)		
				20.1-23.0	D(1991)	29.0	S(1979)		
				21.0	J(1981)	18.0	S(1979)		
				7.0-12.0	WC (1987)	22.0-24.0	S(1979)		
				13-16	WC (1987)				
				27.0	WC (1987)				
				22-25	WC (1987)				
				14.1	WC (1987)				
				20.9	WC (1987)				
				19.9	WC (1987)				
				18-20	WC (1987)				
				12.3-13.8	WC (1987)				
				13.5-18.8	WC (1987)				
				17.6-20.2	WC (1987)				
				16.1-24.2	WC (1987)				

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				25.0	WC (1987)				
				17.0	WC (1987)				
				6.3	WC (1987)				
				8.0	WC (1987)				
				22.0	WC (1987)				
				5.4	WC (1987)				
				6.3	WC (1987)				
				7.0-8.0	WC (1987)				
				11.0-17.0	WC (1987)				
				14.0-19.0	WC (1987)				
				18.0-21.0	WC (1987)				
				20.0-24.0	E(2009)				
Percopsidae									
Trout-Perch	*Percopsis omniscomaycus*			16.0-18.0	WC(1987)			22.9	WC (1987)
				15.0-16.0	WC(1987)				
				7.0-16.0	WC(1987)				
				7.0-8.0	WC(1987)				
				10.0-16.0	E(2009)				
				16.0	WG(1991)				
Petromyzontidae									
Sea Lamprey	*Petromyzon marinus*	15.0	WC(1987)	14.3	WC(1987)	31.40	WG(1991)		
		20.0	WC(1987)	6.0-15.0	WC(1987)				
				6.0	WC(1987)				
Salmonidae									
Atlantic Salmon	Salmo salar	15.1	J(1981)	14.0	J(1981)	27.8	P(1993)	32.9	B(2000)
		12.1	J(1981)	18.0	J(1981)	27.5	G(1973)	32.6	B(2000)
				12.0-16.0	E(2009)			32.8	B(2000)
								32.7	B(2000)
Bloater	*Coregonus hoyi*	18.6	EF(1997)	7.0-10.0	WC(1987)	26.0-27.0	WC(1987)		
Brook Trout	*Salvelinus fontinalis*	13.0	J(1981)	13.8	J(1981)	25.3	WW(2007)	28.70	WC(1987)
		14.0	J(1981)	15.7	WC(1987)	24.5	WW(2007)	29.80	WC(1987)

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
		16.1	J(1981)	14.8	WC(1987)				
		15.4	WC(1987)	13.0-17.0	E(2009)				
		10.0-15.0	WC(1987)						
Brown Trout	*Salmo trutta*	10.0	J(1981)	17.6	J(1981)	24.7	WW(2007)	25.0	WC(1987)
		15.5	J(1981)	14.3	J(1981)	25.3	WW(2007)	26.0	WC(1987)
		12.0	J(1981)	12.2	J(1981)			29.0	B(2000)
		12.8	J(1981)	17.4	J(1998)			29.8	B(2000)
				15.0-18.0	E(2009)			29.9	B(2000)
								30.00	B(2000)
Chinook Salmon	*Oncorhynchus tshawytscha*	12.0	WC(1987)	11.7	J(1981)	21-22	WC(1987)	25.1	S(1979)
		15.5	WC(1987)	17.3	WC(1987)	21.5	S(1979)		
				12.0-16.0	E(2009)	24.3	S(1979)		
				12.3	J(1998)	25.0	S(1979)		
						25.1	S(1979)		
Chum Salmon	*Oncorhynchus keta*	13.0	J(1981)	14.0	J(1998)				
				14.1	J(1981)				
Coho Salmon	*Oncorhynchus kisutch*	14.8	J(1981)	15.0	J(1981)	9.4	W(1995)	25.0	BG(1979)
		17.0	WC(1987)	11.4	WC(1987)	26.0	S(1979)	24.8	BG(1979)
				16.6	WC(1987)	22.9	S(1979)	25.3	BG(1979)
				13.0-15.0	WC(1987)	23.1	S(1979)	25.9	BG(1979)
				20.0	WC(1987)	24.3	S(1979)	25.8	BG(1979)
				8.0	WC(1987)	25.0	S(1979)	27.7	BG(1979)
				12.0-16.0	WC(1987)			28.1	BG(1979)
				15.6	WC(1987)			28.7	BG(1979)
				14.3	WC(1987)			29.2	BG(1979)
				16.6	WC(1987)			29.6	BG(1979)
				11.0-17.0	E(2009)			27.5	B(2000)
				13.0	J(1981)			29.7	B(2000)
								28.2	B(2000)
								29.2	B(2000)
								29.1	B(2000)
								27.6	B(2000)
								27.9	B(2000)

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
Cutthroat Trout	*Oncorhynchus clarkii*	22.0	W(2009)	14.8-14.9	Mc(2006)	24.0	W(2009)	27.6	B(2000)
		13.4	Mc(2006)			19.7	B(2005)	29.1	B(2000)
		14.2	Mc(2006)					29.9	B(2000)
								25.5	B(2000)
Lake Herring, Cisco	*Corengus artedii*	18.1	J(1981)	18.5	J(1981)	19.8	S(1979)		
				13.7	J(1998)	21.2	S(1979)		
				9.9	J(1981)	24.3	S(1979)		
				10.0	WC(1987)	26.8	S(1979)		
				7.2	WC(1987)	25.8	S(1979)		
				13.0	WC(1987)	26.0	WG(1991)		
				13.0-18.0	WC(1987)				
				9.0-14.0	WC(1987)				
				16.5	WG(1991)				
				7.0-10.0	E(2009)				
Lake Trout	*Salvelinus namaycush*	10.0	J(2001)	11.8	WC(1987)	23.5	NSFA(2007)		
		5.0-15.0	J(2001)	12.0	WC(1987)	25.1	WC(1987)		
				10.0	WC (1987)				
				14.0	WC (1987)				
				9.0-13.0	E(2009)				
Lake Whitefish	*Coregonus clupeaformis*	13.5	J(1981)	12.7	J(1981)	20.6	S(1979)		
		15.8	J(1981)	12.0-16.0	J(1981)	22.7	S(1979)		
				8.0-14.0	E(2009)	25.8	S(1979)		
				13.0	WC (1987)	26.6	S(1979)		
Pink Salmon	*Oncorhynchus gorbuscha*	15.5	J(1981)	11.7	J(1981)				
				13.0-17.0	E(2009)				
				11.7-12.8	J(1981)				
Rainbow Trout	*Oncorhynchus mykiss*	17.2	WC (1987)	13.6	J(1998)	21.50	WC(1987)	17.50	WC(1987)
		16.5	WC (1987)	18.7	J(1998)	26.60	WW(2007)	26.70	WG(1991)
		17.0	WC (1987)	19.7	J(1998)	25.60	WW(2007)		
		12.0	WC (1987)	18.9-21.7	WC (1987)	26.20	WW(2007)		
				13.0	WC (1987)				
				16.5	WC (1987)				
				11.3	WC (1987)				

Common Name	Scientific Name	OGT	Reference	FTP	Reference	UILT	Reference	CTMax	Reference
				14.0	WC (1987)				
				15.8	WC (1987)				
				17.5	WC (1987)				
				22.0	WC (1987)				
				11.6	WC (1987)				
				12.6	WC (1987)				
				5.0-17.0	WC (1987)				
				12.0-18.0	E(2009)				
Round Whitefish	*Proposium cylindraceum*			17.5	WC (1987)				
				3-5.8	WC (1987)				
				2.1-3.6	WC (1987)				
Sockeye Salmon	*Oncorhynchus nerka*	15.0	J(1981)	14.1	J(1981)	8.9	W(1995)		
				10.0-15.0	WC (1987)	26.8	USBR(2007)		
				14.4	J(1998)	28.8	USBR(2007)		
Sciaenidae									
Freshwater Drum	*Aplodinotus grunniens*	22.0	WC (1987)	21.0-31.0	D(1991)	32.8	S(1979)	34.0	S(1979)
				26.5	WC (1987)				
				19.6	WC (1987)				
				21.1-26.1	WC (1987)				
				22.0	WC (1987)				
				29.0-31.0	WC (1987)				
				22.0-30.0	WC (1987)				
				6.0-11.00	WC (1987)				
				24.0-28.0	E(2009)				
Umbirdae									
Central Mudminnow	*Umbra limi*			28.9	WC (1987)				
				38.0	WC(1987)				

Table A2. *Reproductive thermal data (optimum spawning temperature [OS] and optimum egg development temperature [OE]) for 87 Canadian freshwater fish species. Values for events (e.g. hatching) and life stages (eg. embryo survival) other than spawning are taken to be representative of egg development. A dash (-) indicates that no data were found. Species are arranged alphabetically within families. All temperatures are recorded in °C. References are provided in an Appendix reference list that follows the tables.*

Common Name	Scientific Name	Event	Optimum Temperature	Temperature Range	References
Acsipenseridae					
Lake Sturgeon	*Ascipenser fulvescens*	embryo survival	12.0-17.0	-	W (1985)
		spawning	14.0-16.0	-	WC (1987)
Amiidae					
Bowfin	*Amia calva*		-	-	-
Anguillidae					
American Eel	*Anguilla rostrata*		-	-	-
Catostomidae					
Bigmouth Buffalo	*Ictiobus cyprinellus*	spawning	15.5-18.3	-	SC(1973)
		spawning	17.0	-	WC (1987)
		hatching	-	14-27	WC(1987)
Longnose Sucker	*Catostomus catostomus*	spawning	-	5.0	SC(1973)
		hatching	-	10.0-15.0	SC(1973)
		spawning	-	15.0	-
		spawning	-	12.0-23.0	WC(1987)
		hatching	-	17.4	WC(1987)
Quillback	*Carpoides cyprinus*		-	-	-
Spotted Sucker	*Minytrema melanops*		-	-	-
White Sucker	*Catostomus commersoni*	spawning	10.0	-	WC(1987)
		incubation/hatch	15.0	-	WC(1987)
		spawning	17.8	-	WC(1987)
		spawning	11.2	-	WC(1987)
		spawning	23.4	-	WC(1987)
		spawning	16.8	-	WC(1987)
Centrarchidae					
Black Crappie	*Pomoxis nigromaculatus*	spawning	19.0-20.0	-	SC(1973)
		spawning	17.8-20	-	WC(1987)
		hatching	18.3	-	WC(1987)
Bluegill	*Lepomis macrochirus*	spawning	-	-	WC(1987)
		hatching	22.2-23.9	-	S(1979)
		spawning	25.0	-	WC(1987)
		hatching	22.0-24.0	-	WC(1987)
Green Sunfish	*Lepomis cyanellus*	spawning	-	15.6-28.0	WC(1987)
		spawning	-	20.0-24.0	WC(1987)
		hatching	29.1	-	WC(1987)
Largemouth Bass	*Micropterus salmoides*	spawning	15.6-21.0	-	-
		hatching	20.0	-	-
		spawning	-	-	-
		spawning	20.0	-	-

Common Name	Scientific Name	Event	Optimum Temperature	Temperature Range	References
Pumpkinseed	*Lepomis gibbosus*	spawning	-	-	-
		spawning	28.0	-	WC(1987)
		spawning	24.0	-	WC(1987)
		hatching	28.0	-	WC(1987)
Rock Bass	*Ambloplites rupestris*		-	-	-
Smallmouth Bass	*Micropterus dolomieui*	spawning	18.0	-	WC(1987)
		spawning	-	-	WC(1987)
		spawning	-	-	WC(1987)
		egg/larval development	21.0	-	WC(1987)
White Crappie	*Pomoxis annularis*	spawning	18.0-20.0	-	WC(1987)
		spawning		-	WC(1987)
		spawning	16.0-20.0	-	WC(1987)
		hatching		18.3-20.0	WC(1987)
		spawning	14.0-16.0	-	WC(1987)
Clupeidae					
Alewife	*Alosa pseudoharengus*	spawning	12.9-13.1	-	WC(1987)
		spawning	13.0-16.0	-	WC(1987)
		embryo development	17.8	-	WC(1987)
Gizzard Shad	*Dorosoma cependianum*	spawning	22.0	-	WC(1987)
		hatch	22.2	-	WC(1987)
Cottidae					
Deepwater Sculpin	*Myoxocephalus thompsoni*		-	-	-
Fourhorn Sculpin	*Myoxocephalus quadricornis*		-	-	-
Mottled Sculpin	*Cottus biardii*	spawning	12.8	-	WC(1987)
		hatching	-	-	WC(1987)
		spawning	10.0	-	SC(1973)
Slimy Sculpin	*Cottus cognatus*		-	-	-
Spoonhead Sculpin	*Cottus ricei*		-	-	-
Cyprinidae					
Blackchin Shiner	*Notropis heterodon*		-	-	-
Blacknose Dace	*Rhinichthys atratulus*		-	-	-
Bluntnose Minnow	*Pimephales notatus*		-	-	-
Carp	*Cyprinus carpio*	spawning	19.0-23.0	-	WC(1987)
		hatching	23.4	-	WC(1987)
		spawning	27.0	-	WC(1987)
Central Stoneroller	*Campostoma anomalum*		-	-	-
Common Shiner	*Notropis cornutus*		-	-	-
Creek Chub	*Semotilus atromaculatus*		-	-	-
Emerald Shiner	*Notropis atherinoides*	spawning	24.0	-	SC(1973)
		hatch	23.9	-	WC(1987)
Fallfish	*Semotilus corporalis*		-	-	-
Fathead Minnow	*Pimephales promelas*	spawning	-	15.6-17.8	SC(1973)
		hatching	25.0	-	SC(1973)
		spawning		15.6-28.9	WC(1987)
Finescale Dace	*Chrosomus neogaeus*	spawning	-	-	WC(1987)

Common Name	Scientific Name	Event	Optimum Temperature	Temperature Range	References
		hatching	20.0	-	WC(1987)
		Spawning	-	15.0-22.0	WC(1987)
Golden Shiner	*Notemigonus crysoleucas*	spawning	20.0	-	SC(1973)
		spawning	20.0-21.0	-	WC(1987)
		hatching	20.0	-	R(1997)
Goldfish	*Carassius auratus*	spawning	-	18.4-24.9	SC(1973)
		hatching	-	15.5-18.4	WC(1987)
		spawning	-	17.0-24.0	WC(1987)
Longnose Dace	*Rhinichthys cataractae*	spawning	11.7	-	SC(1973)
		hatching	15.6	-	SC(1973)
Northern Redbelly Dace	*Chrosomus eos*		-	-	-
Pugnose Shiner	*Notropis anogenus*		-	-	-
Rosyface Shiner	*Notropis rubellus*	spawning	-	26.1-28.9	SC(1973)
		spawning	-	20.0-22.2	SC(1973)
		hatching	21.1	-	SC(1973)
Spotfin Shiner	*Cyprinella spiloptera*		-	-	-
Spottail Shiner	*Notropis hudsonius*	spawning	20.0	-	WC(1987)
		hatching	20.0	-	WC(1987)
		spawning	18.0	-	WC(1987)
Esocidae			-	-	-
Grass Pickerel	*Esox americanus vermiculatus*	spawning	7.2-11.7	-	SC(1973)
		hatching	7.8-8.9	-	SC(1973)
Muskellunge	*Esox masquinongy*	hatching & development	-	8.0-19.0	WC(1987)
		spawning	12.8	-	SC(1973)
Northern Pike	*Esox lucius*	spawning	-	4.0-19.0	WC(1987)
		hatch	6.4-17.7		S(1979)
Fundulidae			-	-	-
Banded Killifish	*Fundulus diaphanus*	spawning	23.0	-	SC(1973)
		hatching	-	22.0-26.7	SC(1973)
Mummichog	*Fundulus heteroclitus*		-	-	-
Gadidae					
Burbot	*Lota lota*	spawning	0.6-1.7	-	SC(1973)
		hatching	8.0-10.0	-	-
Gasterosteidae					
Brook Stickleback	*Culaea inconstans*	spawning	-	8.0-19.0	SC(1973)
		hatching	18.3		SC(1973)
		spawning	-	4.5-21.0	WC(1987)
Ninespine Stickleback	*Pungitius pungitius*		-	-	-
Threespine Stickleback	*Gasterosteus aculeatus*	hatching	19.0	-	SC(1973)
		spawning		5.0-20.0	WC(1987)
Hiodontidae					
Mooneye	*Hiodon tergisus*		-	-	-

Common Name	Scientific Name	Event	Optimum Temperature	Temperature Range	References
Ictaluridae					
Black Bullhead	*Ictalurus melas*		-	-	-
Brown Bullhead	*Ameiurus nebulosus*	spawning	21.1	-	SC(1973)
		hatching	-	20.6-25.0	WC(1987)
Channel Catfish	*Ictalurus punctatus*	spawning	26.7	-	SC(1973)
		hatching	-	15.6-27.8	SC(1973)
		spawning	23.9	-	WC(1987)
		hatching	-	23.9-22.8	WC(1987)
		spawning	27.0	-	WC(1987)
		hatch		18.0-29.0	WC(1987)
Stonecat	*Noturus flavus*		-	-	-
Yellow Bullhead	*Ictalurus natalis*		-	-	-
Lepistosteridae					
Longnose Gar	*Lepisosteus osseus*		-	-	-
Spotted Gar	*Lepisosteus oculatus*		-	-	-
Moronidae					
White Bass	*Morone chrysops*	eggs	-	11.0-23.9	WC(1987)
		spawning	14.7-16.3	-	WC(1987)
White Perch	*Morone Americana*	spawning	15.6-19.4	-	WC(1987)
		eggs	19.0-20.9	-	WC(1987)
Percichthyidae					
Striped Bass	*Morone saxatilis*		-	-	-
Percidae					
Eastern Sand Darter	*Ammocrypta pellucida*		-	-	-
Rainbow Darter	*Ethestoma carolineum*		-	-	-
Sauger	*Stizostedion canadense*	spawning	9.0-15.0	-	WC(1987)
		spawning	9.0	-	WC(1987)
		spawning	10.0	-	WC(1987)
		incubation/hatch	12.0-15.0	-	WC(1987)
Walleye	*Stizostedion vitreum*	spawning	8.0	-	WC(1987)
		hatching	9.0-15.0	-	WC(1987)
		spawning	6.0-12.0	-	WC(1987)
		hatching	17.8-19.4	-	WC(1987)
		spawning	6.1-8.3	-	WC(1987)
		spawning	3.4-10	-	WC(1987)
Yellow Perch	*Perca flavescens*	spawning	12.0	-	WC(1987)
		incubation/hatch	10.0-20.0	-	WC(1987)
		spawning	7.8-12.2	-	WC(1987)
		spawning	5.0-6.0	-	WC(1987)
		spawning	6.0-12.0	-	WC(1987)
Percopsidae					
Trout-Perch	*Percopsis omniscomaycus*		-	-	-
Petromyzontidae					
Sea Lamprey	*Petromyzon marinus*	spawning	14.4-15.6	-	SC(1973)
		spawning	15.7	-	WC(1987)
		eggs	18.5	-	WC(1987)

Common Name	Scientific Name	Event	Optimum Temperature	Temperature Range	References
Salmonidae					
Atlantic Salmon	*Salmo salar*		-	-	-
Bloater	*Coregonus hoyi*		-	-	-
Brook Trout	*Salvelinus fontinalis*	embryo	6.1	-	estimated from R(1997)
		spawning	10.7	-	WC(1987)
Brown Trout	*Salmo trutta*	spawning	-	6.7-8.9	SC(1973)
		embryo	-	0.0-15.0	WC(1987)
Chinook Salmon	*Oncorhynchus tshawytscha*		-	-	-
Chum Salmon	*Oncorhynchus keta*		-	-	-
Coho Salmon	*Oncorhynchus kisutch*	spawning	-	4.4-7.7	WC(1987)
		embryo	0.9-13.4	-	R (1997)
Cutthroat Trout	*Oncorhynchus clarkii*			-	
Lake Herring, Cisco	*Coregonus artedii*	spawning	3.3	-	SC(1973)
		incubation	5.6	-	SC(1973)
Lake Trout	*Salvelinus namaycush*		-	-	-
Lake Whitefish	*Coregonus clupeaformis*	spawning	-	0.5-9.4	WC(1987)
		hatching	-	-	S(1979)
		hatching	2.2-7.7	-	R(1997)
Pink Salmon	*Oncorhynchus gorbuscha*	spawning	10.0	-	SC(1973)
		embryo	1.0-13.5	-	R(1997)
Rainbow Trout	*Oncorhynchus mykiss*	spawning	6.0-8.0		WC(1987)
		egg development	5-6-12.2		WC(1987)
Round Whitefish	*Proposium cylindraceum*	spawning	4.5		SC(1973)
		egg survival	1.0-5.0		WC(1987)
		spawning	3.0		WC(1987)
Sockeye Salmon	*Oncorhynchus nerka*	spawning		5.0-10.5	SC(1973)
		embryo	1.0-15.5		R(1997)
		spawning		7.0-12.0	WC(1987)
Sciaenidae					
Freshwater Drum	*Aplodinotus grunniens*	spawning	21.0		WC(1987)
		hatching	23.9		WC(1987)
		spawning	21.0		WC(1987)
Umbridae					
Central Mudminnow	*Umbra limi*	-	-	-	-

Table A3. *Spawning season, reproductive guild, and temperature preference class data for 87 Canadian freshwater fish species. Species are arranged alphabetically within families. References are provided in an Appendix reference list that follows the tables.*

Family	Common Name	Scientific Names	Spawning Season	Reference	Reproductive Guild	Temperature Preference Class	Reference
Ascipenseridae	Lake Sturgeon	*Ascipenser fulvescens*	Spring	SC(1973)	A.1.2	cold/cool	C(2001)
Amiidae	Bowfin	*Amia calva*	Spring	SC(1973)	B.2.5	warm	C(2001)
Anguillidae	American Eel	*Anguilla rostrata*	N/A*	SC(1973)	A.1.1	cool	C(2001)
Catostomidae	Bigmouth Buffalo	*Ictiobus cyprinellus*	Spring	SC(1973)	A.1.5	warm	C(2001)
	Longnose Sucker	*Catostomus catostomus*	Spring	SC(1973)	A.1.3	cold	C(2001)
	Northern Hog Sucker	*Hypentelium nigricans*	Spring	SC(1973)	A.1.3	warm	C(2001)
	Quillback	*Carpoides cyprinus*	Spring	SC(1973)	A.1.6	cool	C(2001)
	Spotted Sucker	*Minytrema melanops*	Spring	SC(1973)	A.1.3	warm	C(2001)
	White Sucker	*Catostomus commersoni*	Spring	SC(1973)	A.1.3	cool	C(2001)
Centrarchidae	Black Crappie	*Pomoxis nigromaculatus*	Spring	SC(1973)	B.2.5	cool	C(2001)
	Bluegill	*Lepomis macrochirus*	Spring	SC(1973)	B.2.3	warm	C(2001)
	Green Sunfish	*Lepomis cyanellus*	Spring	SC(1973)	B.2.3	warm	C(2001)
	Largemouth Bass	*Micropterus salmoides*	Spring	SC(1973)	B.2.5	warm	C(2001)
	Pumpkinseed	*Lepomis gibbosus*	Spring	SC(1973)	B.2.2	warm	C(2001)
	Rock Bass	*Ambloplites rupestris*	Spring	SC(1973)	B.2.3	cool	C(2001)
	Smallmouth Bass	*Micropterus dolomieui*	Spring	SC(1973)	B.2.3	warm	C(2001)
	White Crappie	*Pomoxis annularis*	Spring	SC(1973)	B.1.4	cool	C(2001)
Clupeidae	Alewife	*Alosa pseudoharengus*	Spring	SC(1973)	A.1.4	cold	C(2001)
	Gizzard Shad	*Dorosoma cepedianum*	Spring	SC(1973)	A.1.2	cool	C(2001)
Cottidae	Deepwater Sculpin	*Myoxocephalus quadricornis*	Fall	SC(1973)	B.2.3	cold	C(2001)
	Fourhorn Sculpin	*Myoxocephalus quadricornis*	Fall	SC(1973)	B.2.3	cold	C(2001)
	Mottled Sculpin	*Cottus biardii*	Spring	SC(1973)	B.2.7	cold	C(2001)
	Slimy Sculpin	*Cottus cognatus*	Spring	SC(1973)	B.2.7	cold	C(2001)
	Spoonhead Sculpin	*Cottus ricei*	Fall	SC(1973)	B.2.7	cold	C(2001)
Cyprinidae	Blackchin Shiner	*Notropis heterodon*	Spring	SC(1973)	A.1.5	cool/warm	C(2001)
	Blacknose Dace	*Rhinichthys atratulus*	Spring	SC(1973)	A.1.3	cool	C(2001)
	Bluntnose Minnow	*Pimephales notatus*	Spring	SC(1973)	B.2.7	warm	C(2001)
	Carp	*Cyprinus carpio*	Spring	SC(1973)	A.1.5	warm	C(2001)
	Central Stoneroller	*Campostoma anomalum*	Spring	SC(1973)	A.2.3	cool/warm	C(2001)
	Common Shiner	*Notropis cornutus*	Spring	SC(1973)	B.2.3	cool	C(2001)
	Creek Chub	*Semotilus atromaculatus*	Spring	SC(1973)	A.2.3	cool	C(2001)
	Emerald Shiner	*Notropis atherinoides*	Spring	SC(1973)	A.1.1	cool	C(2001)

Family	Common Name	Scientific Names	Spawning Season	Reference	Reproductive Guild	Temperature Preference Class	Reference
	Fallfish	*Semotilus corporalis*	Spring	SC(1973)	A.2.3	cool	C(2001)
	Fathead Minnow	*Pimephales promelas*	Spring	SC(1973)	B.2.7	warm	C(2001)
	Finescale Dace	*Chrosomus neogaeus*	Spring	SC(1973)	A.1.4	cool	C(2001)
	Golden Shiner	*Notemigonus crysoleucas*	Spring	SC(1973)	A.1.5	cool	C(2001)
	Goldfish	*Carassius auratus*	Spring	SC(1973)	A.1.5	warm	C(2001)
	Longnose Dace	*Rhinichthys cataractae*	Spring	SC(1973)	A.1.3	cool	C(2001)
	Northern Redbelly Dace	*Chrosomus eos*	Spring	SC(1973)	A.1.5	cool/warm	C(2001)
	Pugnose Shiner	*Notropis anogenus*	Spring	SC(1973)	A.1.3	cool	C(2001)
	Rosyface Shiner	*Notropis rubellus*	Spring	SC(1973)	A.1.3	warm	C(2001)
	Spotfin Shiner	*Cyprinella spiloptera*	Spring	SC(1973)	A.1.4	warm	C(2001)
	Spottail Shiner	*Notropis hudsonius*	Spring	SC(1973)	A.1.6	cold/cool	C(2001)
Esocidae	Grass Pickerel	*Esox americanus vermiculatus*	Spring	SC(1973)	A.1.5	warm	C(2001)
	Muskellunge	*Esox masquinongy*	Spring	SC(1973)	A.1.5	warm	C(2001)
	Northern Pike	*Esox lucius*	Spring	SC(1973)	A.1.5	cool	C(2001)
	Banded Killifish	*Fundulus diaphanus*	Spring	SC(1973)	A.1.5	cool	C(2001)
	Mummichog	*Fundulus heteroclitus*	Spring	SC(1973)	A.1.4	cold	C(2001)
Gadidae	Burbot	*Lota lota*	Fall	SC(1973)	A.1.2	cold/cool	C(2001)
Gasterosteidae	Brook Stickleback	*Culaea inconstans*	Spring	SC(1973)	B.2.4	cool	C(2001)
	Ninespine Stickleback	*Pungitius pungitius*	Spring	SC(1973)	A.1.3	warm	C(2001)
	Threespine Stickleback	*Gasterosteus aculeatus*	Spring	SC(1973)	B.2.4	cold	C(2001)
Hiodontidae	Mooneye	*Hiodon tergisus*	Spring	SC(1973)	A.1.2	cool/warm	C(2001)
Ictaluridae	Black Bullhead	*Ictalurus melas*	Spring	SC(1973)	B.2.3	warm	C(2001)
	Brown Bullhead	*Ameiurus nebulosus*	Spring	SC(1973)	B.2.7	warm	C(2001)
	Channel Catfish	*Ictalurus punctatus*	Spring	SC(1973)	B.2.7	warm	C(2001)
	Stonecat	*Noturus flavus*	Spring	SC(1973)	B.2.7	warm	C(2001)
	Yellow Bullhead	*Ictalurus natalis*	Spring	SC(1973)	B.2.7	warm	C(2001)
Lepisosteidae	Longnose Gar	*Lepisosteus osseus*	Spring	SC(1973)	A.1.5	warm	C(2001)
	Spotted Gar	*Lepisosteus oculatus*	Spring	SC(1973)	A.1.5	warm	C(2001)
Moronidae	White Bass	*Morone chrysops*	Spring	SC(1973)	A.1.4	warm	C(2001)
	White Perch	*Morone americana*	Spring	SC(1973)	A.1.4	warm	C(2001)
Percichthyidae	Striped Bass	*Morone saxatilis*	Spring	SC(1973)	A.1.2	cold	C(2001)
Percidae	Eastern Sand Darter	*Ammocrypta pellucida*	Spring	SC(1973)	A.1.6	cool/warm	C(2001)
	Rainbow Darter	*Ethestoma carolineum*	Spring	SC(1973)	A.2.3	cool	C(2001)
	Sauger	*Stizostedion canadense*	Spring	SC(1973)	A.1.3	cool	C(2001)

Family	Common Name	Scientific Names	Spawning Season	Reference	Reproductive Guild	Temperature Preference Class	Reference
	Walleye	*Stizostedion vitreum*	Spring	SC(1973)	A.1.2	cool	C(2001)
	Yellow Perch	*Perca flavescens*	Spring	SC(1973)	A.1.4	cool	C(2001)
Percopsidae	Trout-Perch	*Percopsis omniscomaycus*	Spring	SC(1973)	A.1.3	cold	C(2001)
Petromyzontidae	Sea Lamprey	*Petromyzon marinus*	Spring	SC(1973)	A.2.3	cold	C(2001)
Salmonidae	Atlantic Salmon	*Salmo salar*	Fall	SC(1973)	A.2.3	cold	C(2001)
	Bloater	*Coregonus hoyi*	Spring	SC(1973)	A.1.2	cold	C(2001)
	Brook Trout	*Salvelinus fontinalis*	Fall	SC(1973)	A.2.3	cold	C(2001)
	Brown Trout	*Salmo trutta*	Fall	SC(1973)	A.2.3	cold/cool	C(2001)
	Chinook Salmon	*Oncorhynchus tshawytscha*	Fall	SC(1973)	A.2.3	cold	C(2001)
	Chum Salmon	*Oncorhynchus keta*	Fall	SC(1973)	A.2.3	cold	C(2001)
	Coho Salmon	*Oncorhynchus kisutch*	Fall	SC(1973)	A.2.3	cold	C(2001)
	Cutthroat Trout	*Oncorhynchus clarkii*	Spring	SC(1973)	A.2.3	cold	C(2001)
	Lake Herring, Cisco	*Coregonus artedii*	Fall	SC(1973)	A.1.2	cold	C(2001)
	Lake Trout	*Salvelinus namaycush*	Fall	SC(1973)	A.2.3	cold	C(2001)
	Lake Whitefish	*Coregonus clupeaformis*	Fall	SC(1973)	A.1.3	cold	C(2001)
	Pink Salmon	*Oncorhynchus gorbuscha*	Fall	SC(1973)	A.2.3	cold	C(2001)
	Rainbow Trout	*Oncorhynchus mykiss*	Spring	SC(1973)	A.2.3	cold	C(2001)
	Round Whitefish	*Proposium cylindraceum*	Fall	SC(1973)	A.1.3	cold	C(2001)
	Sockeye Salmon	*Oncorhynchus nerka*	Fall	SC(1973)	A.2.3	cold	C(2001)
Sciaenidae	Freshwater Drum	*Aplodinotus grunniens*	Spring	SC(1973)	A.1.1	warm	C(2001)
Umbridae	Central Mudminnow	*Umbra limi*	Spring	SC(1973)	A.1.5	cool/warm	C(2001)

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